Practical Irrigation and Pumping

Water Requirements, Methods of Irrigation and Analyses of Cost and Profit

BY

BURTON P. FLEMING, M.E.

Associate Member American Society Civil Engineers; Head of Department of Mechanical Engineering, State University of Iowa; formerly Irrigation Engineer, Office Irrigation Investigations, U. S. Department of Agriculture

FIRST EDITION
FIRST THOUSAND

NEW YORK
JOHN WILEY & SONS, Inc.
London: CHAPMAN & HALL, Limited
1915

E.V.

PUBLISHERS PRINTING COMPANY
-217 West Twenty-fifth Street, New York

ACKNOWLEDGMENT

The following firms have kindly extended the use of cuts for illustrations:

American Well Works, Aurora, Ill.
Buffalo Steam Pump Co., Buffalo, N. Y.
Byron Jackson Machine Works, San Francisco, Cal.
De La Vergne Machine Works, New York, N. Y.
Fairbanks Morse & Co., Chicago, Ill.
Keystone Driller Co., Beaver Falls, Pa.
Stover Engine Works, Freeport, Ill.

CONTENTS

CHAPTER XI

CHAPTER XII

CHAPTER XIII

CHAPTER XIV

CHAPTER XV

INTRODUCTORY NOTE

To people living anywhere on the American continent west of the hundredth meridian, the practice of irrigation as a fundamental necessity in the production of crops is so common a matter and so thoroughly a part of their daily observation and experience, that they scarcely appreciate the viewpoint of the farmer of the humid regions, who stands more or less aghast at the idea of spending a large sum per acre to secure for the growth of the most common crops that moisture which under his conditions, nature itself provides.

The author does not agree with those, who in the attempt to make a virtue out of a necessity, go so far as to maintain that the lack of moisture which makes irrigation necessary over perhaps one-third of the area of the United States is in reality a blessing. It cannot be denied that the irrigation farmer of the west cultivates a soil in which many important plant foods, leached out by natural rainfall from the soils of the more humid regions, are still retained, making it in general, therefore, a rich and productive soil when water is applied; he is not, for some years at least, and in many locations never will be, bothered by the drainage problem; he enjoys a climate in which the abundance of sunshine makes not only for rapid crop growth, but also for the physical well-being of himself and family while most important of all, perhaps, from the standpoint of agronomy, he can control the moisture supply and he is comparatively free from those seasonal variations in rainfall and temperature which make farming in the great valley of the Mississippi, for example,

so uncertain an enterprise. On the other hand, it can neither be denied nor evaded that these advantages are secured and the region made habitable, only by the expenditure of comparatively large sums of money in developing the natural water resources, in preparing the land for irrigation and applying the water. All of these expenses the irrigation farmer must bear over and above those numerous and sometimes heavy financial burdens attending actual crop production in more humid regions, while securing also the advantages of education, public improvements, and the protection of government. This additional financial burden under which the irrigation farmer labors is therefore a real one, and that he bears it complacently, is able to pay a comparatively high rate of interest on farm mortgages, finance extensive public improvements, such as good roads, and maintain school systems quite the equal of those in more fully settled localities in the humid regions, is evidence that the advantages accruing through irrigation, as above noted, are tangible and have a money-earning or real economic value.

The cost of irrigation is enormous. It is estimated by the census of 1910 that up to July 1 of that year, about $308,000,000 had been spent by private and public or quasi-public enterprises in reclaiming the 14,000,000 acres under cultivation by irrigation in the West. It is this tremendous investment, simply in the means of supplying moisture for growing crops, that excites the wonder of the farmer or banker of the humid sections, at the ability of the Western communities to stand the strain, for under whatever arrangement the various irrigation projects are or have been financed it must not be forgotten that all eventually are paid for by the products of irrigated land. Certainly an appreciation of the meaning of the figures above cited, should impress upon the Westerner the tremendous

importance and extent of the subject of irrigation which he usually takes so much as a matter of course.

The sum above mentioned has been spent almost entirely in the development of means of supplying farms with water by gravity methods of distribution, but it is significant of the rapidity with which development is proceeding in the arid West that the pumping of water for irrigation purposes is attracting more and more attention each year and already it is estimated that 250,000 H.P. of pumping engines and motors are engaged in this work, that nearly $9,000,000 have been expended in the necessary plants, while the acreage capable of being irrigated amounts to over 260,000 acres.

In California and certain other sections favorable to the growth of citrus fruits the pumping of water for the irrigation of lands not otherwise susceptible of irrigation has been a common practice for many years and the means and appliances have been well worked out. In other parts of the West, however, it is only comparatively recently that farmers have thought seriously of attempting to irrigate on a commercial scale by any other means than that of conveying surface water to the land by gravity. The water was diverted from a surface stream or taken from a storage reservoir. Land irrigated or susceptible of irrigation by gravity canals has become in the course of time so high in price, or so scarce, or the means necessary for gravity irrigation have become so expensive, that at present the chance is very small for the man of strictly limited resources to secure a foothold in any of those parts of the West already well developed. There still remain, of course, vast areas of land whose latent agricultural possibilities merely wait the touch of water to make such land immensely productive. Much of it lies either on the higher benches or mesas adjacent to irrigated

valleys and above high-line canals, or it is found in numerous localities where topographic and climatic conditions preclude the presence of surface streams. Such land, in many cases, may be homesteaded, or if in private ownership may be bought at prices ranging from $5 to $40 per acre, depending upon how successfully it or other lands in the neighborhood have been "dry farmed." Where such land has beneath it a water-bearing formation, and general economic conditions are favorable, we have a location suitable for the profitable development of a scheme of irrigation by pumping. Other locations equally favorable may often be found where it is possible to pump water from a high-line canal upon land lying above the canal, and in other cases, where a long and expensive canal may be necessary to reach a suitable location for head-works, a careful study of the problem may show that a decided saving in first cost and operation as well as maintenance, will result from the installation and operation of a pumping plant to place water upon high-lying land adjacent to a surface stream. Particularly may this be so if there is a possibility of generating the power necessary for pumping at some near-by point where the conditions favor an inexpensive hydro-electric development and transmitting the power thus developed to the most feasible location for the pumping plant. It is not improbable that, if there were any assurance that the necessary skilled attendance for such a plant would be always provided, it would pay some irrigation concerns with which the writer is familiar to abandon their present long and costly canal lines, now so difficult to maintain, install a pumping plant and either buy the necessary power or build a simple hydro-electric plant themselves. If properly installed and maintained such plants would be sure to obviate those serious losses frequently sustained through canal breaks, which are a

common occurrence in the very midst of the irrigation season, on canals located in canyons with very steep cross slopes and in unstable or porous material.

In this connection, it may be stated that a remarkable development has occurred within the past few years in the installation of irrigation pumping plants in Idaho and Oregon, along the Snake River, where, because of its slope

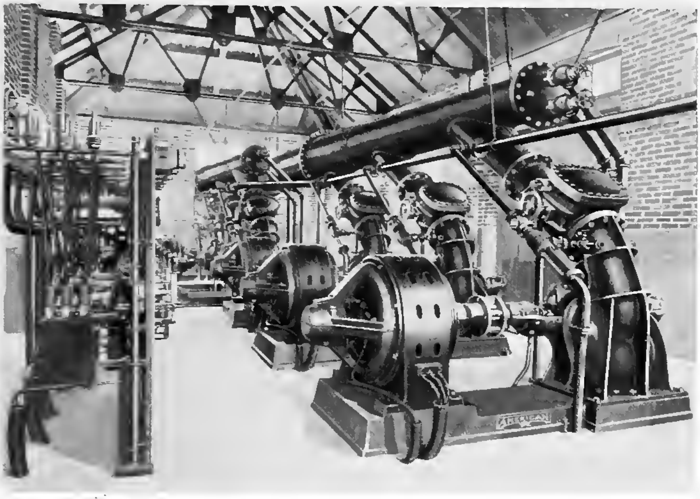


FIG. 1.—A high-grade pumping plant on the Snake River, eastern Oregon. This plant is supplied with current at 66,000 volts and has eight motors of total capacity of 1,150 horse-power driving centrifugal pumps with aggregate working capacity (normally five pumps in operation) of over 22,000 gallons per minute. The water is raised to three elevations, 55, 84, and 110 feet above the supply canal which conveys water to the plant about 3,600 feet inland from the river. This plant exhibits probably the most advanced example of mechanical design in irrigation work in the West.

and the configuration of the valley, gravity systems are very expensive. Electrical power is being generated in large amounts on the river and its tributaries by several competing companies and is sold at from $20 to $28 per horse-power for the irrigation season. Several very large electrically driven plants have recently been con-

structed which pump water from the river upon lands lying as much as 150 feet above, and in areas as large as 15,000 acres, requiring as much as 3,000 H.P. in one plant. In the vicinity of Payette, Idaho, a very unusual development of this phase of irrigation is found, there being about 160 plants in a length of 20 miles along the river, utilizing from 2 to 1,000 H.P. each. A large number of the plants lift water from a high-line canal upon orchard lands lying above the canal, while others divert directly from the river. Nearly all of these plants have electrically driven centrifugal pumps and many fine fruit ranches depend entirely upon them for water supply.

Before any decision can or should be reached with regard to the feasibility of a pumping-plant project, a careful and systematic study should be made of the matter in all its phases. This applies to the small individual plant as well as to the large central plant, perhaps with greater force to the former since such plants often represent the entire working capital of an individual who stakes his future upon the success of his venture. Ill-considered plans, wrong and costly types of machinery, too high a "pumping head," and a disregard of such simple factors as nearness to markets and suitable crops to grow with high-priced water have contributed, in the many cases which have come under the writer's observation, to the lack of success attending a pumping-plant investment. It is not enough that there shall be cheap land and a water-bearing stratum beneath it, or some other adjacent source of water supply. This water must not be at great depth below the surface to be irrigated or the source be so far away that long pipe lines are required; otherwise it will not pay with any ordinary crop to develop the water supply, however extensive or unfailing it may be. The crop grown must in any case be one requiring relatively little water, and must

give high crop value per acre, while the machinery used should be of such type as will give the service desired with a maximum of running economy and a minimum of maintenance charges.

It will be the endeavor of the writer in the present volume, to consider the irrigation problem chiefly from the pumping standpoint, treating of those matters which interest the man considering the installation of a small pumping plant from both the standpoints of design and operation. It is hoped further that the author's suggestions will be helpful to the contractor who specializes in the machinery of pumping plants and be of some assistance to the engineer who is called upon to design the central station plant. Beginning with estimates of water requirements of different crops on different soils and in different localities, the writer will consider in turn: the matter of wells and well-sinking; pumps and pumping machinery suitable for different depths and volumes together with typical designs for certain assumed conditions; prime movers including a discussion of oil engines, gas producers, etc.; windmill irrigation, chiefly from standpoint of co-relation between wind velocities and pump size; the question of cost and profit in pumping and a method of estimating the latter for certain conditions; and, finally, the central station plant and its possibilities. An attempt will be made to make the discussion as general as the nature of the subject will allow, but where specific instances or trade names are thought helpful they will be given.

The writer brings to his aid in the preparation of this volume an experience of over eight years in irrigation work, during which time he has covered most of the Western States, and has had much opportunity to observe and study irrigation conditions. He has had the benefit of considerable direct personal experience (some of it rather bitter,

indeed) in the matter of irrigation pumping and on several questions connected therewith is able to give the results of experimental work.

The writer has drawn his data freely from government reports, experiment station bulletins, particularly those written by himself, and various other sources specifically mentioned in the text.

PRACTICAL IRRIGATION AND PUMPING

CHAPTER I

THE AMOUNT OF WATER REQUIRED

The Difficulties in the Solution of the Problem.—A necessary preliminary to the consideration of any problem in the water supply for irrigation, is a more or less definite knowledge of the amount of water required in the irrigation of the particular crops it is desired to grow upon the particular lands it is desired to irrigate. At the outset, one is confronted with a difficulty in securing definite information upon the matter, due to the fact that most of the data we have on what has been called "The duty of water," has been obtained by investigations made on gravity systems. Except under exceptionally well-managed canal systems, especially those where the water user is charged on the basis of the amount used, at a certain price per acre-inch* or acre-foot,* there is always a temptation for the irrigator to use more water than is really necessary because it costs him little or nothing and he usually works under the time-honored delusion that "The more water the more crop." Moreover, most measurements have been taken where but little or no attempt has been made to eliminate seepage losses in distribution, and where but little attention is paid

* The acre-inch is the amount of water which without loss of any sort would cover a level area of one acre to the depth of one inch. The acre-foot is twelve times this amount.

to the prevention of loss through leaky and imperfect ditches or field laterals. Consequently results obtained under these conditions are not to be considered comparable with those bound to follow when the irrigator realizes that every revolution of the pump by which the water is raised, represents a definite amount to be deducted from the returns of the crop grown and where consequently we are apt not to find pumped water escaping from fields into adjacent roadways or pouring through breaks in poorly built laterals while the irrigator discusses politics with his neighbor. Although therefore, so far as the crops themselves are concerned, the water requirement is the same whatever the source of the water supply or the method of distribution, the human element which enters into the problem makes it possible in estimates to allow a very much higher duty for pumped water than for water derived from surface sources. If in connection with the pumping plant a reservoir is used and losses in distribution are prevented by employing pipe or concrete distributaries and if, also, great care is observed in laying out the fields in such a way as to reduce evaporation and needless seepage to a minimum, the amount of water needed for a crop may be but little more than its absolute water requirement.

Amount Used Affected by Skill of Irrigator.—The amounts of water found to be used in the irrigation of crops, when supplied by the gravity systems, present considerable variations in different localities due to differences in climatic conditions, topography as affecting surface or subterranean drainage, soil porosity, the character of distribution, and finally the skill of the irrigator. It is the opinion of the writer, based on his own measurements and upon observations made in various parts of the West under considerable range of altitude and latitude, that the irrigator's skill has probably a greater effect upon duty of water measurements

than have any or perhaps all of the other conditions mentioned above. That is to say that a careless irrigator in a northern climate may use more water in the irrigation of a crop grown upon a dense soil than would a careful irrigator use for the same crop on a deep sandy soil in the intensely hot valleys of New Mexico or Arizona. The best the engineer can do, therefore, especially when designing a gravity system, is to base his estimates upon averages, not forgetting that local irrigation customs and practices may change easily the values subsequently obtained in the practice of the water users by 25 to 50 per cent.

Amounts of Water Actually Used.—The writer has measured the duty of water on fields of alfalfa in western Nebraska and southern Wyoming where 52 acre-inches per acre were used and he has seen abundant alfalfa crops grown in New Mexico with 40 inches. Likewise he has also observed conditions in New Mexico where irrigators thought it impossible to grow a crop of alfalfa on less than 60 acre-inches.

In the following table are given limiting values of the duty of water from various crops as determined in different localities with gravity systems.

TABLE I

DUTY OF WATER, VARIOUS CROPS, GRAVITY SYSTEMS
ACRE-INCHES PER ACRE

Alfalfa	Corn	Wheat	Oats	Orchards Small Fruits	Garden Truck Patches
36 to 60	24 to 30	18 to 26	18 to 24	18 to 20	30 to 36

The quantities in the table are based upon averages secured by measurements made at the edge of the field. The duty at head-gate of the main canal will increase the

above values by 30 to 50 per cent. due to seepage and evaporation losses in distribution.

Periods of Irrigation for Different Crops.—Probably as satisfactory a basis of estimate as it is possible to obtain in figuring upon water requirements is as to the number of times a crop must be irrigated and the probable amount supplied at each watering. This is for the reason that practice in regard to such common crops as are included in the above table is pretty well standardized, and the number of irrigations necessary or desirable will not be found to vary appreciably from the mean for any given locality. Thus in the case of alfalfa,—in the northern climates this crop will make two and sometimes three cuttings; in the southwest, four generally and sometimes five cuttings are secured. The number of cuttings is also of course influenced by altitude. The common practice is to give this crop a thorough irrigation at the beginning of the season to get it well started, a second previous to the first cutting, a third shortly after the crop has been removed, not until the fresh growth has attained a height sufficient to give it some protection against excessive evaporation and scalding, a fourth about a week or ten days before the second cutting, and so on for each succeeding cutting. Thus each cutting will secure at least two irrigations, or the number of irrigations will be about double the number of cuttings. It might be said in passing, that usually in the growing of alfalfa, rainfall, unless most unusual in amount, has but little effect upon the practice of irrigation, and rarely will cause the irrigator to miss a regular watering or will diminish appreciably the amount of water which should be used during a perfectly dry season.

Practice in regard to grain crops is more variable, depending upon locality, amount of rainfall, etc. In most cases an irrigation is necessary either just before or imme-

diately after plowing and planting in order that moisture conditions may be proper for germination. A second irrigation will follow possibly at the end of two weeks or seventeen days, and the third and usually the final is given while the grain is in the milk. An extra watering may be necessary between the second and third mentioned, in the absence of normal summer rains, thus giving a minimum of three and a maximum of four irrigations for wheat, oats, barley, flax, etc.

Corn, sorghum, and Kaffir corn are crops usually requiring less water than broad culture crops, since they are cultivated more or less frequently, thus preventing rapid soil evaporation, besides which there soon is formed in the process of growth a dense shade further reducing soil evaporation. Three irrigations are usually found ample for such crops.

Orchards require less water per acre than most crops, due to the fewer number of plants per acre and to the fact that greater care ordinarily is taken in distribution in orchards. Usually three and not to exceed five irrigations are given and the tendency is towards the lower limit when proper cultural conditions are maintained.

Truck gardens, owing to the greater sensitiveness of the plants to unfavorable moisture conditions, must be irrigated with care and with not excessive amounts of water. Thus, although the truck garden may need to be irrigated over the entire area from six to eight times or possibly more during a season, yet the amount of water used will probably be less than that required for a broad culture crop or one which is deep-rooted.

Amount of Water at Each Irrigation.—Nothing is better known by the irrigator of extensive experience than that "it does not pay" to use a small stream of water or a "small head of water" in irrigation. A small stream seems to dissipate and lose itself when one attempts to spread it

over an extensive area, so that if a certain volume is available, as for example, 1 acre-foot, it might be found impossible to spread this amount uniformly over 2 acres with a small stream, no matter how carefully the land had been prepared or what its character. On the other hand, with "a good irrigation head" as he would call it, a skilled irrigator would without difficulty distribute the acre-foot over the acre and probably secure great uniformity in its distribution, so that no one part would be soaked and another part be left practically dry. The difficulty in distribution may be said to increase even on well-prepared land as the total quantity applied decreases. Experiments conducted by the writer on sandy open mesa soil, showed that it was next to impossible to secure uniform distribution even on small carefully prepared plats, with less than 3 acre-inches of water per acre at an irrigation, and that very much greater success was attained when 4 acre-inches were applied at an irrigation.

In actual experience under gravity irrigation systems where water is used with but little thought of economy, 5 and 6 acre-inches are usually applied per acre at an irrigation of alfalfa, 5 acre-inches with grains, 3 to 4 with orchards, and about 3 with truck patches. It will be seen, therefore, that in general, 3 acre-inches is the probable minimum which may be allowed per irrigation, even under the careful system of irrigation which must be assumed as existing or will exist under a pumping project, and for most cases, probably 4 acre-inches would represent the value attained by the average irrigator even when impressed, as every one using pumped water should be, with the supreme necessity for economy in its use.

Best Size of Irrigating Stream.—Although, as suggested in a previous paragraph, a small "irrigating head" is uneconomical, on the other hand, large streams are equally

conducive to waste when too large for an irrigator to handle properly. The size of stream which one man may handle, will be determined entirely by the character of crop being irrigated, the thoroughness with which the land is prepared for irrigation, its slope, and the character of the soil. Each of these conditions is more or less dependent upon the other; thus with a grain crop the same care in preparing the land would not be necessary or expected as in the case of a melon crop. However, in the case of alfalfa or grains, where well-defined furrows do not exist, a larger stream could be used to advantage than would be desirable for furrow irrigation, and again a crop on land carefully leveled and prepared, could be irrigated by one man with a larger stream flow than where the surface is so uneven as to require considerable of the irrigator's time and skill to conduct water to the high spots. Also on sandy, open soil, one man could handle a large stream to less advantage than a small one, due to the greater tendency of the water, in the former case, toward erosion both of field and laterals, a condition not existing on an adobe or dense loam soil.

In general, one man may handle streams of the sizes given by the following table on different soils and with the special methods of irrigation pertaining to the crops indicated.

TABLE II

Maximum Number of Gallons per Minute, Which One Man May Handle Successfully in Irrigation

	Sandy Soil	Dense or Heavy Soil
Alfalfa	450-600	600–900
Grains	400–500	500–700
Orchard	300–450	400–500
Truck Garden	250-300	300–350

The minimum-sized stream with which a man may do good work is 200 gallons per minute under usual conditions, and if a flow no greater than this can be secured from a pumping plant it will be better, in general, to store several hours' or even days' supply in a tight reservoir and use a large stream for a short time rather than attempt to accomplish anything with so small a stream. The question of reservoirs will be more fully considered in a subsequent chapter.

Acres per day, Irrigated.—It is of some importance in figuring costs of irrigation and in estimates on sizes, to know how much acreage the average irrigator may cover with irrigation streams of different sizes when applying various quantities per acre. The following diagram will enable this to be determined graphically.

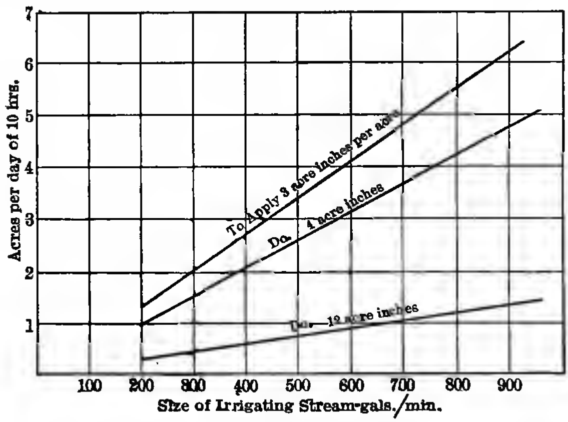


DIAGRAM 1

Showing the Acreage Which One Man May Cover with Irrigating Streams of Different Sizes and Applying Various Quantities

It will be noted by the diagram that when applying 4 acre-inches per acre with a 900-gallon-per-minute stream, one

man may cover nearly 5 acres. This acreage is to be considered about the average maximum performance of one man on well-prepared ground and the table will be found to correspond with the experience of practical irrigators generally, though some variation is to be expected according to local conditions.

Amount of Pumped Water to Allow per Acre.—Summarizing what has been said in previous paragraphs, we may state the case briefly as follows:

1. Pumped water will be used with greater care than water supplied by gravity because of its recognized greater cost.
2. For a successful practice the quantity applied per irrigation cannot be less than 3 acre-inches per acre, but need rarely exceed 5 acre-inches.
3. The number of irrigations during the season will depend upon the crop grown, the locality, the soil conditions, the rainfall—with some crops—and to a considerable extent will depend upon local irrigation customs and practices.
4. Using the average number of irrigations and assuming 5 acre-inches per acre per irrigation for alfalfa, and 4 acre-inches per acre for all other crops, we may prepare the following table to show the probable duty of water for various crops, grown under average climatic and soil conditions with pumped water.

The following quantities are to be regarded as ample only where the greatest care is taken to prevent losses in distribution and where the most advanced ideas in cultivation and soil treatment are adopted and put into practice to prevent unnecessary losses by evaporation and seepage.

On very gravelly soils newly put in cultivation double the quantities below given might scarcely suffice

TABLE III

PROBABLE DUTY OF PUMPED WATER

Crop	Alfalfa per Cutting	Small Grains Season	Corn Season	Sorghum Kaffir Corn Season	Orchard Small Fruits Season	Melons Season	Truck Garden Season
Acre-inches per acre.	10	12	20	26	12	24	24–30

Dry Farming Methods an Aid to Irrigation.—We cannot too strongly emphasize the fact and shall refer to it from time to time, that financially successful irrigation farming with pumped water is only possible when the idea is thoroughly ground home that pumped water is expensive and the same methods and practices cannot be allowed in irrigation with pumped water, as prevail on farms supplied from gravity canals. Only by adopting and following the best practices of dry farmers in the conservation of soil moisture, will the farm ledger show a satisfactory profit when pumped water is used for irrigation. This is true under any circumstances, but applies with special force to those cases where the total lift of pumped water equals or exceeds 50 feet.

For orchard fruits, of course, or special crops such as melons, it is profitable to use water pumped from any reasonable depth, but considerable exercise of good judgment and first-class business management are necessary to wring a profit out of a pumping plant under other conditions.

CHAPTER II

SOURCES OF SUPPLY

Legal Considerations Surrounding Use of Surface Sources.—Careful investigation should be made of the proposed source of supply, to determine its adequacy for the proposed scheme and the nature of any legal or physical difficulties likely to be encountered, before any serious consideration is given to the construction or economic details of a pumping project. In those instances where it is proposed to pump water from a flowing stream or an existing canal, the legal right to the use of the water should first be looked into. If the source proposed be a natural flowing stream or river, much care and attention should be paid to securing this lawful right to the use of water, if the project lies in any of the states where water laws other than the doctrine of riparian rights exist and are enforced. Where the old common-law doctrine of riparian rights exists it is doubtful if any scheme having in view the abstraction of water from a flowing stream and its use in the irrigation of adjacent land would be regarded by the courts as lawful.

In the arid states, on the other hand, where the right to appropriate and use the water of flowing streams and other natural sources is recognized, the procedure usually consists in making application to the State Engineer (in certain prescribed ways) for the right to appropriate a definite quantity of water, at a definite point, for a designated purpose. If the proposed scheme does not conflict with other rights on the same stream, the application will be granted under certain conditions as to diligence in construction of the necessary works and bona-fide use of the

water so obtained in beneficial ways. In those instances where it is proposed to pump water from an existing canal or reservoir, a contract may be arranged with the owners of the same for the right either to a continuous flow of a definite number of cubic feet per second or a certain number of acre-feet during a season. In the latter case certain stipulations should be made as to the periods in which may be secured the fractional amounts making up the total quantities for the season.

It is suggested that a contract calling for a certain number of acre-feet during the season is likely to be the more satisfactory to the operator of the pumping plant, since, unless a reservoir is provided in connection with the plant, it will be greatly to the advantage of the pumping-plant operator to secure relatively large flows for several short periods during the season, than a small continuous flow throughout the season, although the aggregate amount in acre-feet will be the same. Such a contract is, however, difficult to secure in most cases, and might better be avoided altogether unless some accurate and reliable means of measurement be provided which will be respected by both parties to the contract.

Adequacy of Supply—Surface Sources.—In general, no extensive study need be made of the question of adequacy of supply in the above cases, since the most casual inquiry (except where large areas are involved) will satisfy the engineer or prospective owner as to whether there is likely to be a sufficient water supply for the purposes contemplated. Of course, if the project involves the use of waters of a torrential stream flowing only in times of excessive rainfall, the case is one deserving careful study of all available information as to rainfall (yearly normal, maximum, minimum and periods of fluctuation, rate in heavy storms, run-off, etc.), and as to the physical possibilities and cost

of storage works or reservoirs. It may occasionally be found practicable, in unusually favorable locations, to store flood waters cheaply and pump from the storage basin or reservoir onto adjacent lands, when for any reason a gravity distribution is impossible. Such an undertaking, if of any extent, needs careful study from the standpoint of cost, since, if to the cost of a pumping plant be added that of storage works, the land must be fertile and the crops profitable to pay a reasonable return on the investment.

Legal Considerations—Underground Sources.—The legal side of the other method of securing a supply, namely, by pumping from wells, is not as important as when water is obtained from surface sources; the only apparent legal necessity at present is: to be in lawful possession of the land upon which the plant is constructed.

Doubtless, with an increase in the number of plants in any given section, many interesting legal questions will arise, since there is no doubt whatever but that every additional pumping plant drawing water from the common underflow, impairs the capacity of every other plant within a circle whose radius will be larger as the capacity of the plant is increased. This point is illustrated in many sections of the West, both with flowing or artesian and pumped wells. In the Pecos valley of New Mexico, the number of wells tapping the artesian source has grown so large that nearly all of the first wells sunk, which formerly spouted water many feet in the air, have ceased to flow at all and pumps are necessary at present to bring to the surface, water which now may stand in the well tubes some distance below the ground level.*

---

* In many instances the well casings have been eaten through by corrosion at various depths below the ground level, with the result that

In some districts of California, where pumping has been carried on extensively and thousands of plants are in operation, the level from which water must be pumped has lowered tremendously, indicating, in the absence of structural defects in the wells, that the field has been overdeveloped. In justice to the original and older plants, it is evident that some legal restriction should have been placed upon the construction of others, in case the evident failing and overdevelopment of the field did not of itself deter further exploitation.

Adequacy of Underground Supply.—The location of an underground supply and its probable adequacy when found are both matters largely of guesswork and upon which no one should venture to give an unguarded or definite opinion. There is no subject about which less is definitely known or in which the rules are subject to more exceptions. Although a geologist perfectly familiar with a region may give certain opinions as to the probability of an artesian supply being found and its probable depth, unseen faults or fissures in the underlying strata may completely upset his calculations. On the other hand, there are many successful artesian wells drilled upon the advice and under the inspiration of a local seer or some expert with a "divining rod" which may puzzle the geologists to account for at all. To a greater extent is this true of the shallower subsurface water strata which do not, as in the case of artesian supplies, depend necessarily upon conditions determined by

---

much water now fails to reach the surface and leaks away underground. This not only impairs the capacity of the entire artesian field, but is helping to cause saturation of the soil and subsoil, which has made the alkali and drainage problem in this district a most urgent one. The gradual failure of this heretofore abundant artesian field may therefore be quite as much due to structural defects in the old wells as to the presence of later borings.

geologic formations covering vast areas of country, but rather upon conditions more local in their nature as regards rainfall, surface drainage, and porosity of soil and subsoil; conditions which may vary tremendously in a single township. Beginning in Colorado and extending far into Texas, is a vast extent of territory which as recently as ten or fifteen years ago was considered to be practically without water supply of any character aside from the seasonal rains. Now in this region wells are becoming more numerous each year and gradually a vast country is being transformed from a rather dubious cattle range (due to lack of water) into a country suitable for the habitation of man. One who visited the plains of eastern New Mexico and the Texas Panhandle as recently as ten years ago would scarcely deem it possible that now in this region, serious, sober-minded American farmers by the hundreds should be attempting to make their fortunes by mixed farming, utilizing water pumped from an apparently inexhaustible underground supply for their domestic and stock needs and the few acres of crops. Although few extensive pumping plants are in operation, windmills are seen on every hand and water is encountered at such depths as make it appear reasonable to expect that in the not-distant future, small farms irrigated by water pumped by power supplied from a central source will be a commercial reality. The source of this particular supply is not well determined. The general theory accepted and advertised by real-estate boomers and others interested in the disposal of these lands or in their colonization, is that there is a vast underground river flowing from the distant Rocky Mountains of Colorado toward the Gulf of Mexico and that beneath every acre of this region is to be found sufficient water for its irrigation. Such a theory is doubted by geologists who are inclined to account for the widespread existence of underground water in this

region upon either a slowly moving underflow in connection with some adjacent surface stream or as being a natural underground reservoir filled in past ages and the level of which may be lowered more or less rapidly according as the amount withdrawn by pumps and natural outflow exceeds or is less than the amount reaching the underground reservoir by downward seepage of the natural rainfall.

Geology of Deep Wells.—A cross section of a valley which may be regarded as typical of many western valleys, having both artesian and shallow underground supplies, is

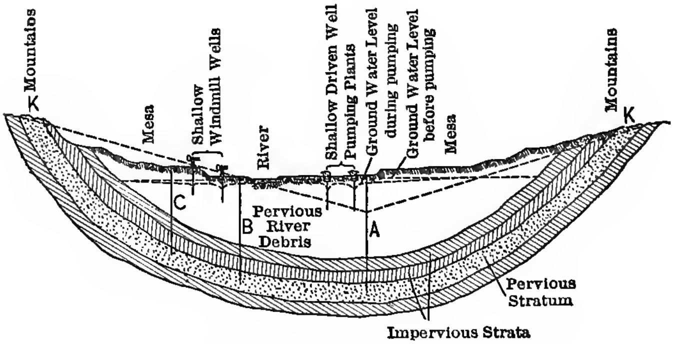


FIG. 2.—A cross section typical of many valleys in the West.

given in Fig. 2. It will be noted that the source of the artesian flow lies in outcroppings of the pervious rock stratum in adjacent mountains and this water, percolating slowly through the porous stratum, will rise to the surface and perhaps give considerable pressure at the outlet of a pipe driven from the valley floor deep into the porous stratum of rock, giving a flowing or artesian well at point A. Other similar wells at B and C will give less flow or may indeed not be flowing wells at all and must be operated with pumps, because the outlet of such wells lies near the hydraulic gradient. Eventually, if a large number of wells

are sunk into the porous stratum the natural flow from the first wells sunk will decrease or may cease altogether, due to the lowering of the hydraulic gradient. Eventually, if pumping is resorted to, in a large number of such wells the demand is likely to exceed the capacity of the porous stratum, the depth from which water must be pumped will become excessive, and pumping will no longer be profitable. The capacity of the artesian field is determined by the areas exposed at K—K through which the rain-water may percolate, the degree of porosity of the water-bearing stratum, and the degree of water-tightness of the upper and nether strata. A pervious stratum of relatively high density will allow of but very slow percolation, due to fluid resistance, so that though considerable pressure may be developed at the surface level of a plugged boring, the amount of water yielded by the well upon removal of the plug will be very meagre. The artesian-well question is largely one of geology and the favorable opinion of a geologist familiar with a region should be obtained before wells are sunk, for although local and unforeseen conditions may, as they have in the past, entirely invalidate a geologist's conclusion and judgment, yet it is only where a hydraulic condition exists similar to that represented by the figure that artesian wells are possible, and before putting money into a hole like an artesian boring it is advisable at least to know whether the probabilities are for or against the success of the venture.

Geology of Shallow Wells.—In a valley similar to Fig. 2 there may be a second body of ground water overlying the first and occupying the porous river débris deposited in the valley trough above the bed rock or impervious strata. This débris is that deposited by the river in past geologic ages, and may consist of alternate horizontal layers of gravel, sand, clay, etc., with occasional pockets of sand or gravel deposited by the ancient river in the same way as

gravel beds and sand shoals are now continually being formed by our modern rivers. This ground water, as it is termed, extends across the valley trough at a surface level corresponding usually to the mean stage of the water in the river, though the level at which ground water may be found is often greatly affected by local conditions such as the presence of large canals on near-by benches, the seepage from which may cause local elevations of the ground-water plane much above the mean level of near-by watercourses or drainage channels. Under normal conditions the ground water will have a surface slope in the direction of the axis of the valley which will be approximately the same as the surface slope of the river and there will be a progressive movement of the ground water downstream, but at a very slow rate, due to the resistance of the materials through which it passes. In case of a rocky ledge or impervious barrier across the valley at any point, a large underground reservoir will be formed above this point and after a long-continued drouth, when the surface stream may have entirely disappeared, ground water will be found at approximately the level of the lowest crest of the barrier. Where there is no barrier, the ground water will continue to flow long after the surface stream is dry and there will be a progressive lowering of level of ground water due to this flow as long as the drouth continues independently of any draught upon the underflow by pumping.

Many streams in the West are torrential and may be very large rivers immediately after heavy rains. During the time of flow of the surface stream a large amount of water percolates downwards and to a less degree laterally into the sandy bed and banks of the stream, and continues its downward course until it reaches an impervious stratum, joins existing ground water, or fills the interstitial spaces in the porous material of the valley trough. Where large

amounts percolate downward, as in sandy stream beds during long-continued floods, the valley bed becomes saturated for great distances from the river, and subsequent to the passage of the flood there will be a subterranean flow continuing for long periods and giving rise to what are truly called "underground rivers." Again, streams may debouch from the mountains onto a sandy plain across which it may flow in times of freshets in a well-defined stream bed, but at other times the stream simply disappears completely into the sands a short distance from the point of debouchure onto the plain and continues its onward movement very much more slowly as an underflow, thus giving rise to such conditions as are found in the Mimbres Valley of New Mexico, where underground water is plentiful, although the Mimbres River, during the greater part of the year, is represented merely by a broad strip of white sand winding across the plain.

Other conditions in which we may find ground water are best represented by a great saucer-like basin filled with pervious materials which absorb the greater part of the yearly rainfall, and in which the ground-water level will rise eventually to the lowest point in the rim of the basin. Such basins usually have a surface topography so flat as to be devoid of extensive or important surface streams, the run-off during periods of heavy rainfall merely running into depressions where it remains until absorbed by the soil or is evaporated. In localities in which such conditions exist water may be encountered at shallow depths, but it is likely to be alkaline, due to the leaching out of soluble salts in the surface layers by the passage of rain-water into the ground water and the gradual concentration of these salts due to lack of drainage. Many such basins are known in the Southwest, of which the most notable is the great Estancia Valley.

CHAPTER III

THE FLOW OF UNDERGROUND WATER

Rate of Flow.—In the preliminary investigations which should precede any underflow pumping project of importance, an inquiry into the adequacy of the supply and the determination of the size and number of the borings, or a decision as to the character of the works by which the supply shall be developed, must necessarily take place first. Such an inquiry must be based first of all upon some knowledge or information as to the rate at which water will percolate through the water-bearing materials to the gathering works.

The rate of flow of the ground water is a matter upon which there has been much speculation and investigation, and although the factors governing the phenomenon are too numerous and too indefinite to make possible a satisfactory prediction for a local case, at least two conditions are known to have a very important effect in determining the rate of flow, namely, the surface slope of the underground stream and the porosity of the materials in which the flow occurs.

Turneaure gives the following table as being applicable to the determination of rate of flow of underground water.

TABLE IV

RATE OF FLOW IN FEET PER DAY

Material	Slope of Water Surface Ft. per Mile					
	10	20	30	40	50	100
Fine sand	0.2	0.4	0.6	0.8	1.0	2.0
Medium sand	1.5	3.0	4.5	6.0	7.5	15.0
Coarse sand	4.0	8.0	12.0	16.0	20.0	40.0
Fine gravel free from sand	20–40	40–80	60–120	80–160	100–200	200–400

If the width of the underground stream and the average depth to the underlying impervious stratum can be determined, and if the slope of the ground-water surface be measured, by the relative elevation of water standing in wells sunk some known distance apart along the axis of flow, some idea of the amount of water passing in the underground stream may be gained by use of the above table, using as arguments slope and character of water-bearing materials. Unfortunately, it is seldom possible to ascertain, even approximately, the vertical and lateral limits of an underground stream and such calculations are apt, therefore, to be of little real value.

The Ground-Water Surface.—When, as is shown in Fig. 2, a number of wells are sunk into the shallow underground supply, there will be during pumping a local lowering of the surface of the underground water which in the absence of pumping is a plane surface, which transversely to the axis of the river extends horizontally at about the level of its mean stage and which in a direction parallel to the river takes its mean slope.

In the case of an underground reservoir the surface of the ground water will of course be level in all directions except during pumping. While pumping is going on, however, the surface will be relieved by a series of approximately cup-like depressions, at the centre of each of which will be a well from which water is being pumped. A vertical section through the centre of one of these depressions will show the intersections with the water surface as a pair of curved lines, hyperbolas A B, C D—Fig. 3, which gradually approach the ground-water plane as they recede from the well.

Revolving one of these curves through a circle will sweep out a volume of which a section is G-A-B-C-D-F. While pumping is in progress, this volume will contain material from which water has been drained, and below

this volume the water-bearing materials will be saturated and a flow of water will be occurring from every direction into the well tube. The rate at which water flows through

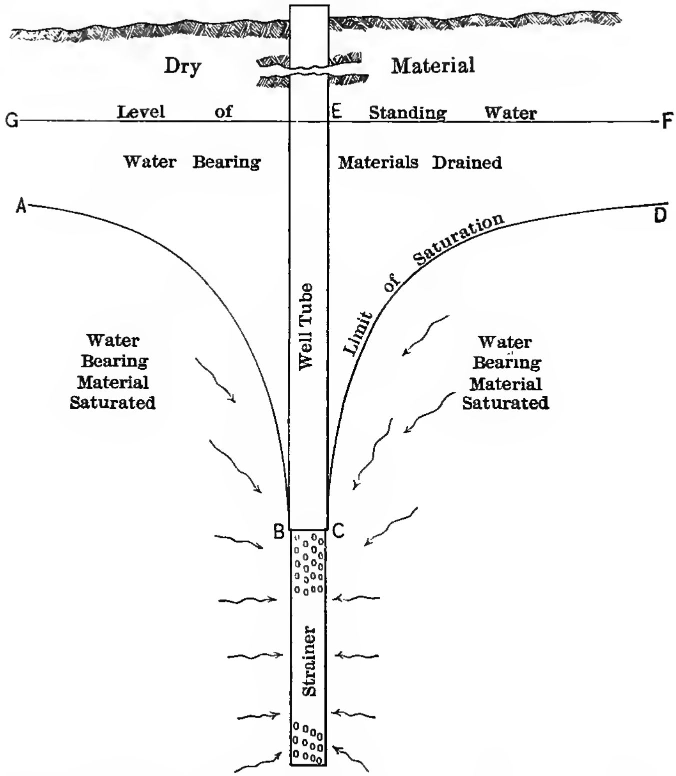


FIG. 3.—Illustrating condition of water-bearing materials surrounding well tube, during pumping.

the water-bearing materials towards the well tube will be a measure of the capacity of the well. This rate depends upon two conditions, namely, the extent to which the water level has been lowered next the well tube or the distance C E and upon the porosity of the material.

"The Draw-down."—The amount of lowering C E or the draw-down, as it is called, determines for a given area of strainer opening, the amount of water which the well will yield for a given porosity of materials. Thus, with the porosity constant, if the draw-down is increased the amount discharged will be increased, and vice versa. Again, if we have two wells, each having the same size of strainer area and yielding the same amount of water, the one located in a porous bed of water-bearing materials will have less draw-down than one in dense materials.

The amount of water which may reach the well depends upon the velocity of water through the water-bearing material, but the laws and constants governing this velocity are not well determined.

Theory of Flow into Driven Wells.—Some investigations into the theory of flow into driven wells reveal several considerations of interest and importance in a practical way, and it may be profitable, therefore, to consider the case where a well is sunk into a water-bearing stratum remote from interference by other wells and in which there is no general horizontal flow of the ground-water, *i.e.*, its surface is level.

Let C D E F, Fig. 4, be a pit sunk to the level of standing water A B, and let G represent a suction tube driven into the water-bearing stratum and then withdrawn to expose a strainer K M. With such an arrangement it is evident that the water may not be drawn down below K and the maximum "draw-down" will be L. The total depth of the stratum from which the supply is drawn is H. Since in general the lines of saturation K N extend steeply upwards at first and then slope away gradually, no very great error is introduced by assuming that the area through which flow occurs has a depth H and that since this area is the product of H and the circumference of a circle whose

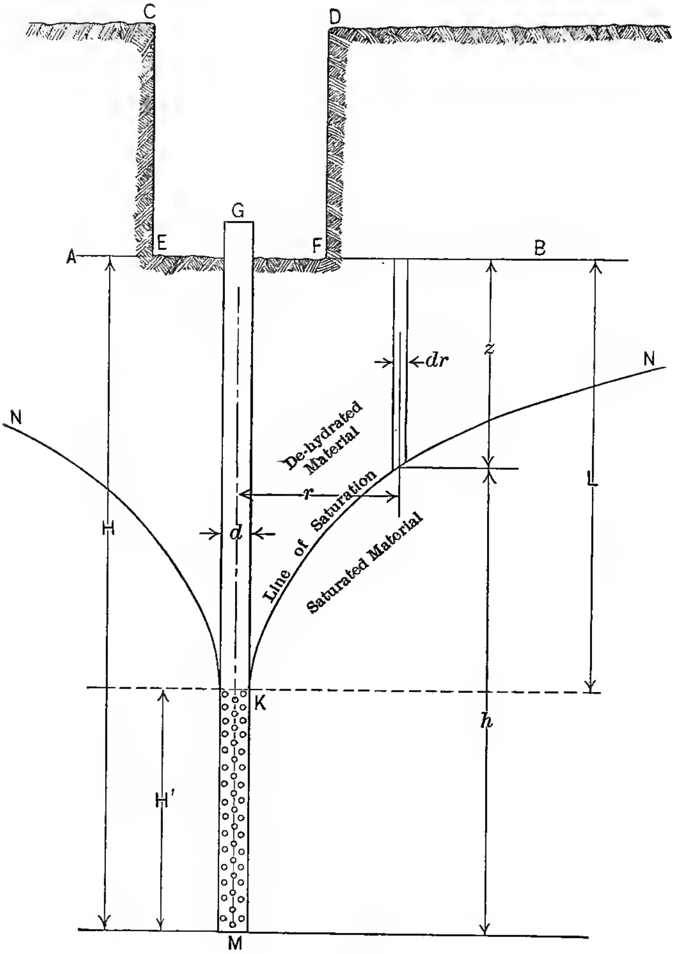

C
D
G
E
F
A
B
z
dr
N
N
De-hydrated
Material
r
Line of Saturation
Saturated Material
H
d
L
K
h
H'
M

FIG. 4.

radius is r, evidently the area will increase directly as r. Hence, if Q is the discharge in any convenient unit, the velocity V at any radius r will be $V = \frac{Q}{2\pi rH}$.*

It has been shown by various experimenters that, for a given character of material, the flow of water through such material is a function of the surface slope, and the porosity. At a radius r from the well tube, let the slope be $\frac{dh}{dr}$ then $V = K\frac{dh}{dr}$ where K = the porosity coefficient and from the above $K\frac{dh}{dr} = \frac{Q}{2\pi rH}$.

From this we find by integration:

$$h - H^1 = \frac{Q}{2\pi KH} \log_e \frac{2r}{d}.$$

Where H^1 = length of strainer
d = diameter of strainer
H = distance of bottom of strainer below the level of standing water
K = a constant depending upon the material.

According to Lembke the values of this constant are as follows:

---

*See Turneaure and Russell's "Public Water Supplies" (Wiley & Sons) for a formula based on the theoretically correct assumption that the annular space through which water flows is governed by the vertical distance from a plane *M* to the saturation line. Such an assumption is avoided in the present discussion, since it leads to an equation extremely difficult to integrate.

Material.	K.
Sand and gravel	9,400
Coarse sand	2,800
Medium sand	760
Fine sand	150

This equation is approximately that of the curve of saturation and for given values of Q, H, and K the value of $h - H^1$ may be determined for various values of r, thus enabling the saturation curve to be plotted as roughly shown in Fig. 3. By this equation but little of practical value can be determined with regard to the probable yield of the well, since too many factors are involved. The yield Q is the quantity desired, but this cannot be found from the above equation except when r is known, and this is usually indeterminable.

However, it is possible to work out a few useful relations based upon the time required to attain a certain draw-down with a given discharge, which will help to clear up the question of how deep to bore a well and what draw-down will be necessary to secure different discharges.

Referring to Fig. 3 we see that a solid of revolution G F D C B A (where G, A, F, and D are located at points where the curve of saturation practically coincides with the water plane) represents at any given time the amount of water which has been pumped up to that time. This volume may be determined by using the equation just determined and integrating for volume. In Fig. 4 consider the differential volume swept through in one revolution by the elementary section of length Z and width d r.

Thus we have:

$$d\,U = 2\,\pi\,r\,Z\,dr$$

But $Z = L - (h - H^1)$; hence we have:

$$d\,U = 2\,\pi\,L\,r\,d\,r - 2\,\pi\,r\,d\,r\,\frac{Q}{2\,\pi\,K\,H}\log_e\frac{d}{2}$$

Let $\frac{d}{2} =$ unity and integrating we have:

$$U = \pi L r^2 - \frac{\pi Q}{2KH} r^2 \log_e r + \frac{\pi Q}{4KH} r^2$$

In this equation r is taken between limits of R and $\frac{d}{2}$ where R is the radius of the circle of influence when h is practically equal to H or $R = e^{\frac{2\pi KHL}{Q}}$. Neglecting values multiplied by $\frac{d}{2}$ we have:

$$U = \pi S \left[10^{\frac{4\pi KHL}{2.3Q}} \right] \left[\frac{L}{2} + \frac{Q}{4\pi KH} \right]$$

where S = per cent. of pore spaces in the water-bearing material.

The Equation for Time of Pumping.—If Q = volume drawn continuously through the well tube in a unit of time, we have:

$T = \frac{U}{Q}$ where T will be in same units of time as Q.

$$\text{Hence}: T = \frac{\pi S}{Q} \left[10^{\frac{4\pi KHL}{2.3Q}} \right] \left[\frac{L}{2} + \frac{Q}{4\pi KH} \right]$$

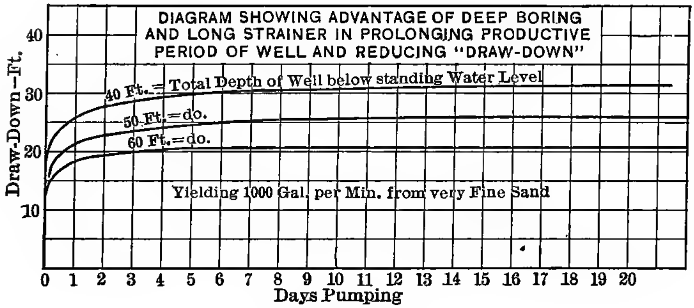


DIAGRAM 2

Using this equation we may compute the draw-down L corresponding to different lengths of time of pumping with

fixed values of Q and soil porosity, and using different values of total depth of well.

In Diagram 2 is shown a series of curves plotted with draw-down against time of pumping for a discharge of 1,000 g.p.m. with a value K = 300, a percentage of porosity of .30, and various draw-downs and depths of well. A series of values for the same quantities are given in Table IV (a).

In this table is seen very clearly the effect of sands of different degrees of fineness upon the yield of the well and the "draw-down." The advantage of deep wells and long strainers in fine material is also shown by this table. It is to be understood that the table is based upon the assumption of a limitless body of underground water with no accessory supply.

The deductions to be made from such a table are as follows:

1. The deeper the well the less the draw-down for a given flow.
2. The longer the strainer the greater the time the well will give the required flow without exceeding the desired or allowable draw-down.
3. In fine material, deep wells and long strainers are essential.

The above equation may also be used to determine approximately the flow which may be expected under a given set of conditions. Thus let it be assumed that it is desired to know what flow can be secured from a well driven 30 feet into the water-bearing stratum and provided with a 10-foot strainer. It is desired that it be possible to pump continuously during six months without the draw-down exceeding the allowable 20 feet. Also the water-bearing material has a porosity of 30 per cent. and an effective size of grain of .2 millimeters.

TABLE IV (a)

Table Showing Number of Days a Well May be Made to Deliver 1,000 Gallons per Minute Before the Water Level is Lowered in Material Surrounding Well Tube to Various "Draw-downs." Well Sunk in Various Materials to Various Depths

Draw-down or depth of lowering in feet	Very fine sand, effective size 0.1 mm.				Medium fine sand, effective size 0.3 mm.				Medium coarse sand, effective size 0.4 mm.				
	Total depth of bottom of well tube below standing water level in feet.												
L	60	50	40	30	60	50	40	30	60	50	40	30	20
2	......	......	....	....	......	....	....	....	......	......	......	......	....
4	......	......	....	....	......	....	....	....	40,000	1,000	25	.63	....
6	......	......	....	....	......	....	....	....	......	......	6,000	240	....
8	......	......	....	....	......	....	....	....	......	......	......	80,000	50
10	.0062	.0025	....	....	1.58	.25	.04	.006	......	......	......	......	25,000
15	.15	.038	.0095	....	610	38	2.35	.15	......	......	......	......	....
20	3.2	0.5	.079	.012	200,000	5,000	125	3.2	......	......	......	......	....
25	63	6.3	.63	.06	......	....	....	....	......	......	......	......	....
30	1170	74	4.6	....	......	....	....	....	......	......	......	......	....
40	400,000	10,000	....	....	......	....	....	....	......	......	......	......	....

TABLE V*

VALUES OF $\frac{K}{2.3}$

	Effective Size of Sand Grains in Millimeters						
Porosity per cent.	.10	.20	.30	.40	.50	.80	1.00
20	22	89	202	358	560	1,430	2,240
25	28	112	252	448	700	1,790	2,800
30	34	134	302	537	840	2,150	3,360
35	39	157	353	627	980	2,570	3,920

Using Table V we find that $\frac{K}{2.3}$ for the porosity and effective size of sand grains is 134.

The involved form of the equation makes it difficult to determine a value of Q for a given value of T, hence it is most easy to assume several values of Q and for the values of T so found plot a curve from which the particular Q for the desired time may be interpolated. Such a curve is shown in Diagram 3.

It will be noted that the value of Q for 180 days is about 225 gallons per minute. The above dimensions and size of sand and porosity were chosen for an example, since they correspond, approximately, to the conditions existing at a 12-inch well sunk by the writer to a depth of 30 feet below the surface of ground water with a strainer 19 feet long where the draw-down rarely exceeded 17 feet. This well yielded by actual measurement from 300 to 350 gallons per minute, a sufficiently close check, in this instance at least, to warrant some faith in the formula and constants. A second curve for a 10-foot greater penetration is also

* Taken from Turneaure and Russell's "Public Water Supplies."

shown in Diagram 3, from which it appears that, for conditions otherwise the same as before, about 300 gallons per minute might be developed for the same limiting draw-down.

Limitations of the Formula.—At best it must be conceded that estimates based upon such a formula as above

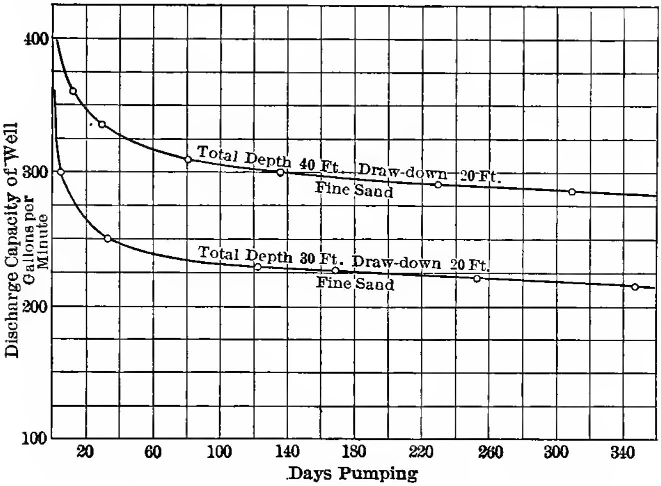


DIAGRAM 3

SHOWING RELATION BETWEEN TIME OF PUMPING, DISCHARGE AND DEPTH OF WELL FOR GIVEN DRAW-DOWN AND WATER-BEARING MATERIALS

derived are but little more than approximations, and before the formula can be applied it is necessary to make a careful investigation of the water-bearing sand to determine its porosity and the effective size of grain.*

With this information at hand the formula may be

* Porosity of the water-bearing material may be determined by placing a quantity of the dry material in a vessel of known volume, shaking it down thoroughly and measuring the volume of water necessary to fill the voids, *i.e.*, the amount which may be poured into the

applied as above illustrated and some idea obtained of the depth necessary to drill the well and the length of strainer necessary for a given capacity. It must be understood, however, that the formula is based on conditions which rarely exist, *i.e.*, an underground reservoir of indefinite extent and no flow occurring other than that due to the draught from the well in question.

The more usual conditions are those encountered in river valleys where a slow movement of water occurs in the direction of the river slope and where consequently the surfaces formed by the lines of saturation will be unsymmetrical on an axis parallel to the stream, being steeper on the upstream side, while a flow will be constantly entering the circle of influence to replace water already pumped out. In such case the formula will probably give slightly smaller values than will actually be realized and the estimate will therefore be on the conservative side.

Interference of Wells.—The above will not hold good where other active wells are within the circle of influence of the one proposed. Thus, in the case previously cited, where H = 30, L = 20, Q = 300 G.P.M. we have

$$R = 10 \frac{2\pi KHL}{2.3\,Q} = 626 \text{ ft.}$$

---

dry material before water flushes to the surface. The ratio of this volume to the total volume of sand is the porosity; thus in a sand of 20 per cent. porosity, 20 per cent. of the volume consists of voids between the particles.

The effective size of grain is an arbitrary but convenient designation for comparing the size of grain in various grades of sand. The effective size of sand grain is the same as the size of mesh in millimeter of that screen which will allow 10 per cent. by weight of a sample of the dry sand to pass through it, but will retain 90 per cent. It is much less than the average size of grain in ordinary sand. The determination of the effective size requires the use of a set of standard millimeter screens and an accurate balance for determining the respective weights.

where R is radius of circle of influence or is the distance from the well at which the line of saturation reaches the level of the normal water plane. If another well of equal size and capacity be located closer than 1,250 feet = 2 R the lines of saturation will cross and the wells will interfere, each cutting down the capacity of the other. The effect of a number of wells in the same locality, sunk into the same water-bearing stratum, is obviously to cause a decrease in the flow of each, and this effect will be the more marked as the distance between them is decreased. Under such circumstances it is difficult, if not impossible, to arrive at any satisfactory estimate of the quantity of water a well will provide, and in this case, as indeed it may be said of any case, the only way to determine properly and with reasonable certain accuracy the capacity of a well is first to bore the well, connect it to a pump and try it, noting not only the quantity of water obtained, but also the draw-down and the length of time the quantity may be pumped without seriously increasing the draw-down.

Practical Limits of Draw-down.—So far in this discussion we have assumed that the draw-down or lowering of level of the ground water in the vicinity of the well may not exceed the feasible suction lift of 20 feet. The draw-down may be made greatly to exceed this limit by placing the pump itself below the normal water plane. Such construction, however, with any sort of pump except the common well or pump cylinder, a vertical turbine pump, or an air-lift, is very expensive in respect to the construction of the well. Moreover, the deep well-pump cylinder has too limited a capacity for the irrigation of other than orchards or truck gardens; the turbine pump is yet very high in price, and the air-lift too expensive in operation. Consequently it may be said that it is not advisable for one contemplating irrigation on a more or less extensive scale by pumping, to

have a greater draw-down than the usual working suction limit of 20 feet, except where orchards are to be grown.

Size of Well Tube.—In the formula derived on page 25 the effect of the size of the well tube upon the discharge was purposely neglected. It may, however, be shown that with other conditions the same, the supply is only slightly increased by a large increase in diameter of well casing.

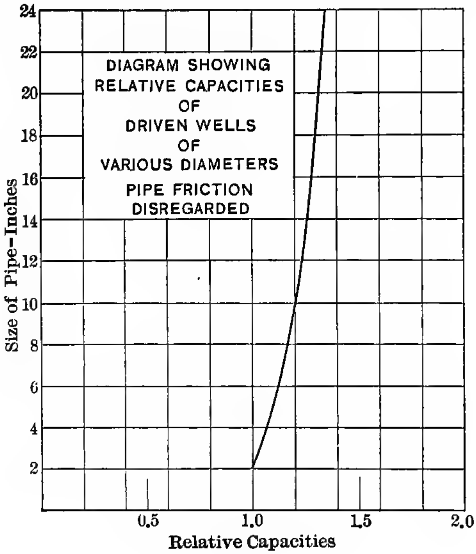


DIAGRAM 4

This is illustrated by above diagram, in which the capacity of a 2-inch well tube is represented by unity and that from other sizes under the same set of conditions by comparative values as represented by the curve. It will be noted that an increase in size from 2 to 24 inches gives only 40 per cent. increase. As the water-bearing material increases in density the comparative increase in capacity is still less for the large-sized casings. This con-

clusion is, of course, independent of frictional effects in the casing itself, and losses in head at entrance, but it confirms what is generally conceded in practice, namely, that the use of very large casing for shallow tubular wells is of doubtful practicability. The experience of the writer leads him to believe that for most irrigation pumping work, 8-inch pipe or casing is the largest which should be used and that not smaller than 3-inch should be adopted for any irrigation work, however small the plant. The recommendation in regard to 8-inch casing is made in view of the fact that this size is about as heavy as can be handled conveniently by the common-size drilling rig and the friction loss for the largest amounts of water which can be developed in a single well, will not be appreciable in the length of casing required for a well of that depth which in the small pumping plant it will be found practicable to sink. In thus stating what he regards as good judgment, the writer has in mind the idea of a small plant installed by an individual or community for irrigation of common crops or for domestic water supply.

Even for large projects, however, common experience is decidedly against the attempt to "corral" a large supply by one large expensive boring. It is far better to sink a large number of small-sized wells to a considerable depth than one large one to the same depth, both from the standpoint of expense and amount of water yielded. Indeed, the large irrigation pumping plant in its most feasible and up-to-date form includes a large number of small wells scattered over the area to be irrigated, each well pumped by a motor operated by electric power transmitted from a central power station. Such a scheme is much more flexible, cheaper in first cost, and in every way more economical and satisfactory even when the area to be irrigated is sufficiently compact and small in extent to make it possible

to distribute water over it from one central point at which the large boring might be located. In passing, it may be said that experience has shown that one thousand gallons per minute is about the largest quantity of water it is feasible to pump from individual driven wells for irrigation purposes.

CHAPTER IV

STRAINERS

Definition.—Referring again to Fig. 4, we see that the portion of the pipe K M, included between the bottom of the boring and the level of the water in the immediately surrounding material at the time of greatest draw-down, should be an area through which water may pass into the well pipe. In certain kinds of material this might be simply an unlined hole, but in the great majority of cases this portion of the well must be a perforated portion of the casing and is called the "strainer." Evidently its only purpose is to prevent caving in of the surrounding material into the well tube. The strainer obviously should in no case extend above the lowest point of draw-down, since in that event air would enter the well tube and destroy the vacuum by which the pump is enabled to cause a flow up the well tube in case the pump is directly connected to the upper end of casing. In case a draught tube is dropped down inside the casing the vacuum will, of course, not be destroyed by the strainer extending above the lower line of draw-down, but the portion of strainer extending above this limit is useless. For this reason, and because the suction limit is about 25 feet, even at low altitudes, the top of the strainer should not extend above that depth below the normal level of standing water.

Special Cases Governing Depth of Strainer.—It sometimes happens that the water-bearing stratum from which it is feasible to obtain water does not extend more than 25 feet below the level of standing water. This case is

illustrated in the following figure in which on the left is shown a quicksand or fine-sand stratum, on the right a

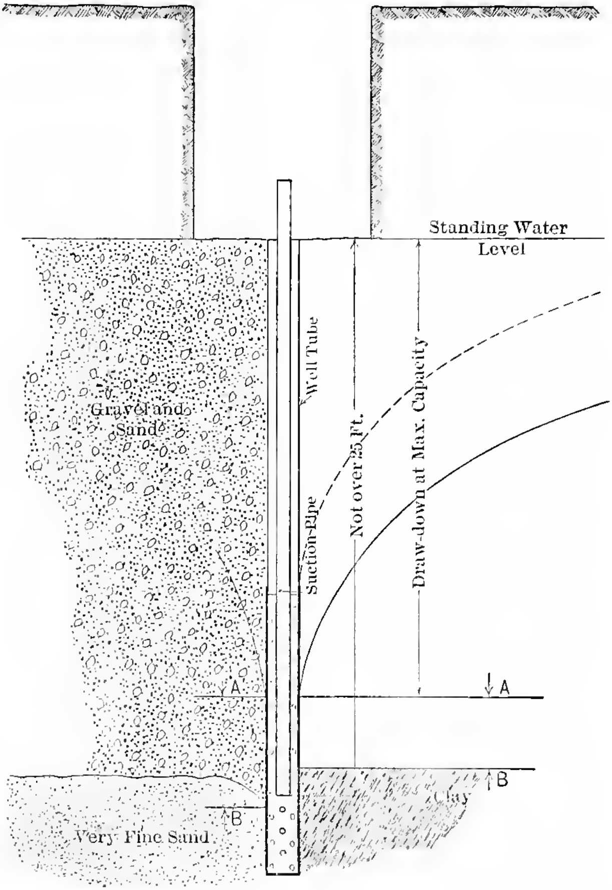


FIG. 5.—Showing use of suction pipe inside of casing to develop shallow water stratum.

clay stratum at a depth of about 25 feet below standing water level, and in either case the boring should of necessity not extend much below the bottom of the gravel stratum.

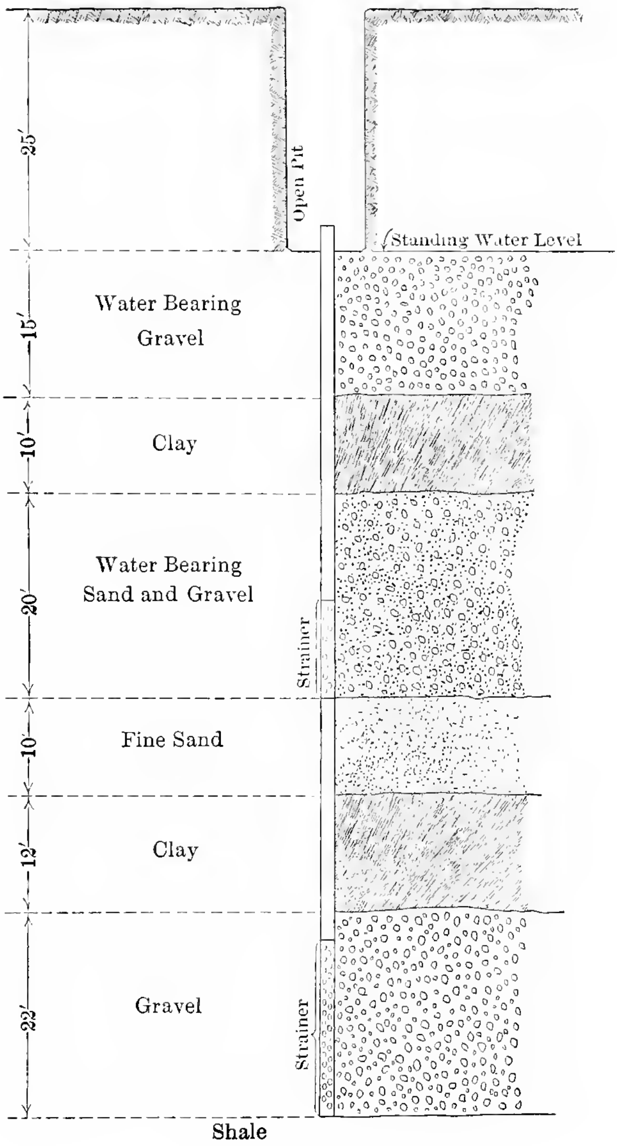

25′
Open Pit
Standing Water Level
15′
Water Bearing
Gravel
10′
Clay
20′
Water Bearing
Sand and Gravel
Strainer
10′
Fine Sand
12′
Clay
22′
Gravel
Strainer
Shale

FIG. 6.

Here a strainer 10 or 12 feet long may be used and a suction pipe lowered inside of the casing so that its inlet is 20 to 25 feet below the level of standing water. Evidently by this means the water level may be drawn down to the limit of suction, but the yield from such a well will be less than from one where a greater length of strainer is exposed, there being a restriction in area and greater loss in head at entrance.

Frequently by drilling to greater depths other favorable water-bearing strata will be encountered, as is illustrated in Fig. 6. In this case, which is taken from an actual well, the first porous stratum below standing water was too shallow for the placing of a strainer, and below this was encountered a 10-foot stratum of clay. Below this, however, was found a splendid bed of gravel, and below this successive strata of clay and gravel, as shown. In this instance the underground conditions were determined by a preliminary boring, after which an 8-inch casing was driven, into which at proper distances along its length were screwed strainers of perforated pipe so located as to intercept the gravel strata as shown. A boring of this character is specially adapted for yielding water suitable for domestic or city supply, owing to the fact that surface water strata which are most likely to be contaminated are cased off and the supply drawn from the deeper and probably purer strata.

Kinds of Strainers.—The strainer itself may be made in a number of ways. Probably the more common strainer is a section of pipe of the same size as the well casing, perforated by drilling throughout its length a great number of small holes. The strainer thus made may be used without further preparation, where the stratum to be intersected is of comparatively coarse gravel and little or no sand. Such strainer should, however, either be galvanized after the holes are drilled, or in case that is not feasible, be well

coated with good asphaltum paint. Where the stratum to be intercepted is of sand, which is the usual condition, it may be advisable to surround the perforated pipe with wire gauze of copper, brass, or galvanized wire, or, as in the case of the Lane strainer, it may be wrapped with a layer of wire, triangular in section, with the apex lying inwards, adjoining wires being separated to provide a continuous narrow spiral slit for the passage of water. Such a strainer is screwed into the length of casing and sunk with it. Strainers with fine-mesh gauze are necessary when the purpose is to exclude sand, as must be done when using a pump with valves.

A strainer of deserved merit, but of entirely different character, is that known as the Porcher. This is much used in the Rio Grande Valley of New Mexico and Texas. It is of heavy galvanized iron sheeting perforated with elongated holes and formed into a cylinder of such size that it will pass easily inside of the well casing used. In the best form the perforations are punched and the tube formed and riveted previous to galvanizing, which insures a strainer capable of resisting corrosion for a considerable length of time. Since this strainer cannot be screwed into the length of casing and sunk with it, the practice is first to sink the casing to a point at which it is desired the bottom of the strainer shall be, a matter to be decided upon by previous exploration or from a knowledge of the character of strata encountered during the process of sinking the casing. The casing having been sunk to this level, the strainer, cut to proper length, is lowered inside of it until its lower end reaches the desired level. The casing is now withdrawn with jacks and the entire length of strainer exposed, less about 6 inches at the top. Obviously, the casing must be in sections of such length that when pulled far enough to expose the strainer, a joint will occur at or near the level

of the ground or the bottom of the open pit in case the latter method has been adopted. The difficulty in withdrawing a casing in some formations, limits the use of this strainer to driven wells not over 50 feet in length of casing. The strainer may be secured in almost any desired length up to 20 feet; since it may be made in sections riveted together, but such a strainer opposes so little resistance to the passage of water that its length for any size of casing probably need not exceed 15 feet. The slots are made of such width as will exclude the smallest gravel encountered and the length of slots is usually from 1 to 1¼ inches, while the widths vary from ⅛″ to ¼″, 3/16 inch being a common size.

It is apparent that such a strainer will not exclude sand, and in the cases where it is used, the practice is, upon completion of the well, thoroughly to flush out the sand by continuous pumping for a number of days. This strainer obviously cannot be used with any pump other than a centrifugal. In a gravel-and-sand stratum, the continuous pumping has the effect of removing the sand from a considerable distance around the strainer, and results in a natural screen of gravel about the strainer which affords free passage for water and results in much greater capacity from the well after some years of use. The amount of sand thus removed is amazing, sometimes amounting to many carloads, and unless special provision is made for taking care of it, considerable trouble may be encountered at first in the clogging of the pump, valves, etc. The Porcher strainer is recommended for wells in cases where the depth of the bottom of the strainer will not exceed 50 feet below standing water level and where the water-bearing formation contains 50 per cent. by volume of gravel greater than ⅛″ in greatest dimension. Where the proportion of gravel is less than this amount, a finer strainer may have to be used, but the writer has seen the Porcher strainer

used in a formation decidedly "quicksand" in character, by pouring in around the top of the strainer, as soon as pumping began, a large quantity of screened gravel, which by reason of its weight took the place of the sand as it was pumped from around the strainer and resulted, eventually, as gravel continued to be added, in the formation of a gravel screen around the strainer, thus enabling water to be pumped comparatively free from sand.

Cook Strainer.—A type of strainer of great merit is that called the Cook strainer, illustrated in Fig. 7. This is constructed of brass, with slots of width adapted to exclude all but the smallest size of water-bearing material. These slots are wider on the inner than the outer periphery of the tube, thus insuring against mechanical clogging of the openings. In certain strongly alkaline water these strainers have sometimes been clogged by deposition of insoluble alkaline matter due to chemical reactions induced by the action of certain ingredients in the water. Before using such a strainer, therefore, it would be well to ascertain, by chemical examination of the water, if such action is apt to occur. In normal waters, of course, the brass strainer will greatly outlast an iron or even galvanized-iron strainer.

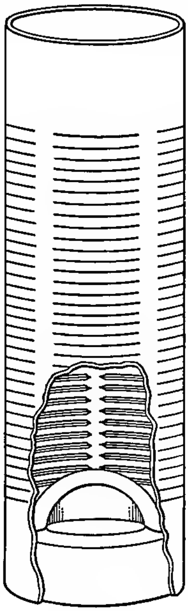


FIG. 7.

Conclusions on Strainers.—In conclusion, with regard to strainers it may be said that:

1. Strainers over 20 feet in length are not considered necessary to develop, in ordinary water-bearing sands and

gravels, the quantity of water which may be secured with usual draw-down of 15 to 25 feet.

2. Open strainers may be used as successfully as fine strainers in gravel and fine sand mixed in about equal proportions by volume, if centrifugal pumps are used and provision is made for taking care of the large quantity of sand which will be pumped during the first year or more of operation.

3. Open strainers may be used in water-bearing formations with large proportion of very fine sand if gravel is poured in around the strainer as pumping progresses.

4. Drive points and gauze strainers should never be used except with small capacity piston or plunger pumps from which sand must be excluded.

CHAPTER V

WELL SINKING

Practical Suggestions.—It will not be within the scope of this work to give more than a few brief suggestions to those contemplating the construction of pumping plants, and who are not familiar with the problem of well sinking, since this is an art itself, and one which demands the exercise of great skill, good judgment, and considerable experience to be carried on successfully. To any one not experienced in the matter, the writer's advice would be to obtain the services of a competent well driller with a good outfit, when any well larger than 3 inches in diameter and over 30 or 40 feet deep is to be driven. Wells of less diameter and less depth may be driven by a resourceful, patient man not provided with the proper well-drilling equipment, but for larger, deeper wells the work is nearly impossible without proper power machinery.

Well-Drilling Machinery.—The type of machinery to employ will be determined, to a large extent, by the character of materials through which the well is to be driven, the size of the casing, and the contemplated depth. The following classification indicates what is usually considered good practice in selection of machinery.

Spudding Machines.—These machines are those most generally employed, since they may be used in a greater variety of materials and to almost any depth of boring or size of casing. They are made in a variety of sizes by a number of well-known firms, among which may be mentioned the American Well Works, Aurora, Ill.; the Key-

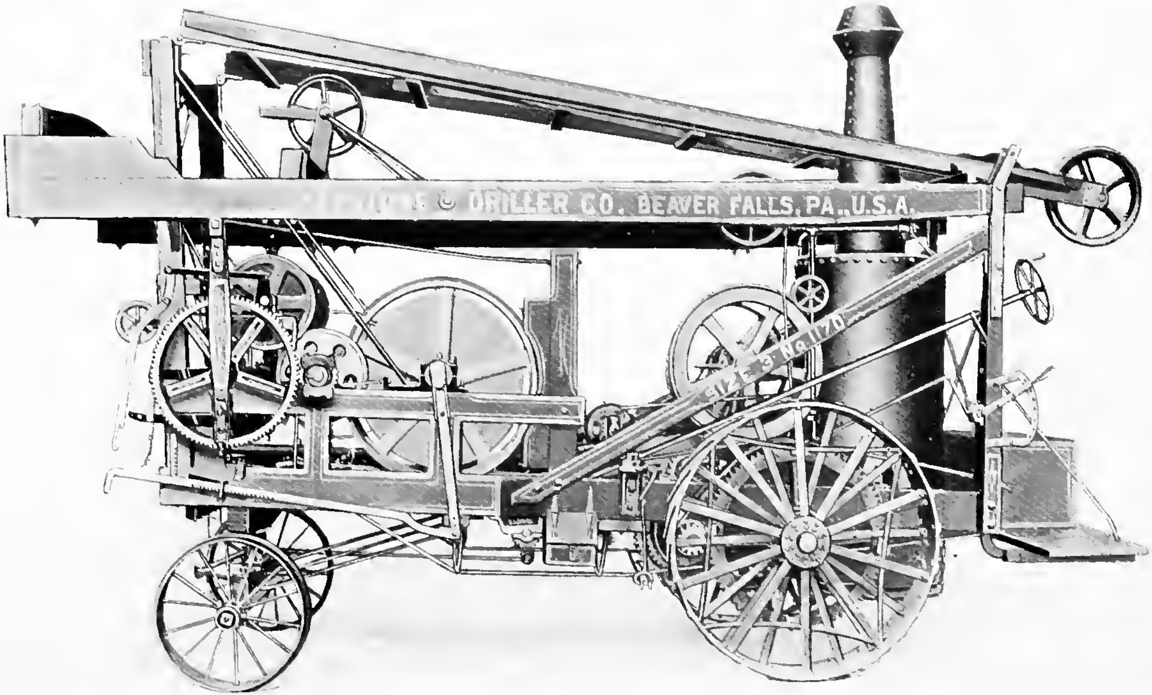


Fig. 8.—Self-propelling spudding machine for general well drilling.

stone Driller Co., Beaver Falls., Pa.; Williams Brothers, Ithaca, N. Y.

A large steam-driven, self-propelling machine made by the Keystone Driller Company is illustrated in Fig. 8.

This machine has capacity to drive 6-inch wells to a total depth of 350 feet, and is listed at about $1,600 with complete equipment F.O.B. factory.

For other wells a variety of equipment from the horse-driven tripping winch to the more costly and efficient machines, will be found listed in the catalogues of the manufacturers mentioned.

Jetting Machines.—These machines are devised to enable more rapid drilling in soft material than is possible with the common churn drilling or spudding machine. They differ but little from the latter in essential particulars, the jetting machine being really a spudding machine additionally equipped with one or more force pumps for sending a stream of water down the boring to the point of the drill. An illustration of a small, easily portable machine of this type shown adapted to be driven by horsepower, is given in Fig. 9.

Such a machine will sink a 3-inch well to a depth of 500 feet and larger sizes proportionately less depth.

Rotary Machines.—Where quicksand or extremely loose alluvial material is encountered, or on the other hand where holes are to be drilled in solid rock, rotary drilling machines are found of great convenience and economy. Such a machine may be made by adding a special attachment to a spudding machine. In the rotary machine the well casing is rotated and the material under the cutting edge is forced out and passes to the surface around the outside of the casing under the action of water forced in at the top of the casing under pressure. The water not only removes the material in the path of the casing, but

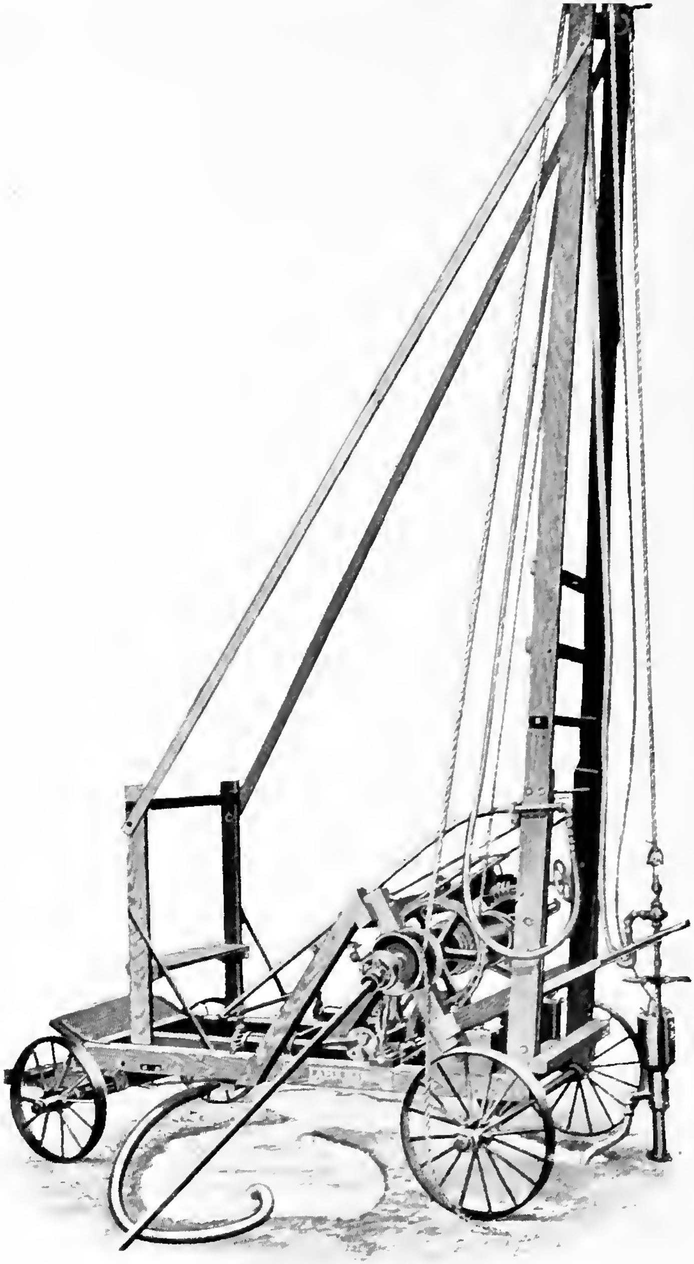


FIG. 9.—A jetting machine of small size.

also erodes a passage around it, allowing it to sink easily and rapidly. Where rock must be penetrated, either a tempered steel saw-tooth cutting-edge tool is placed on the

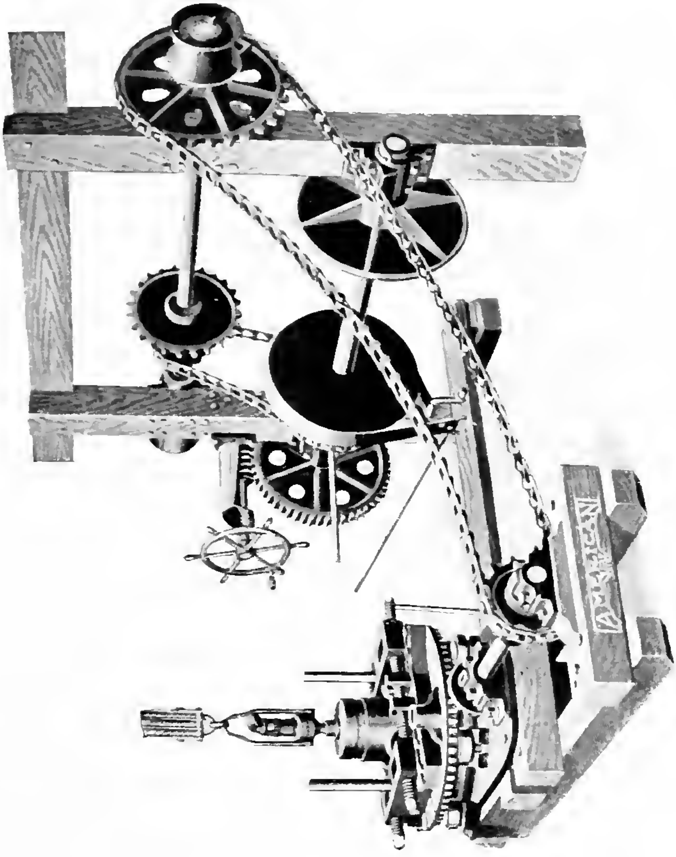


Fig. 10.—Apparatus for rotary drilling of wells. Water is forced into the casing through the swivel connection by which the casing is suspended.

bottom of the pipe, or a special hollow tool is used, the cutting edge of which is studded with some hard material like the diamond, though the diamond drill is being super-

seded by those in which carborundum and such materials are used. In this method of boring through rock, a core is left inside of the pipe or tool and is removed from time to time for examination of the kind of material being penetrated. Such a method of drilling is of evident value in prospecting work, and is very generally employed, also, in investigating the character of underground strata preparatory to the building of high dams, etc. The rotary scheme of drilling is particularly well adapted to the sinking of 8-inch casings to depths of 100 feet or less, such as comprise most of the irrigation wells. Moreover, since it lends itself particularly to the driving of casings into quicksand formations it is of much use where churn drilling and sand bucketing fails or is very slow indeed. Again, since the casing sinks of its own weight, it is possible to jack it up easily after a strainer of the Porcher type has been placed in position. Although it has some disadvantages, it certainly cannot be denied that the rotary process of drilling possesses great merit for the drilling of large, shallow wells for irrigation pumping. A machine for such work as made by the American Well Works and adapted to be attached to a four-leg derrick and driven by chain from a steam or gas engine, is shown in Fig. 10 and Fig. 11.

Operation of Well Sinking.—The actual operation of well sinking need not be gone into with much detail, since no two problems are ever just alike and since it would be useless to point out here all the various operations which must be gone through and the precautions which must be observed in the actual work. The man who expects to drill his own well should make it a point to visit a well being drilled by some experienced well driller, and both by observation and discreet questioning, learn as much as possible of the method before attempting anything in a similar way himself. In general the better way, of course, as before

stated, is to contract the work to a man with a good, practical knowledge of the matter rather than to attempt to do the work oneself except where the well is to be small and comparatively shallow. Some hints, however, to the man who must for any reason attempt the work himself may not be out of place here.

The Well Pit.—Where a centrifugal pump is to be used, it should, for reasons which will be explained later, be set as near the water level as possible, and this usually necessitates placing the pump at the bottom of a pit excavated to the level of standing water. Such a pit should be dug prior to the coming of a well driller, since wells are contracted for on the basis of so much per foot, and there is no advantage in paying for the driving of a pipe from the surface and subsequently excavating around it down to water level, and removing the casing between that point and the surface. The pit may be round or square, but since it should be lined to prevent caving (in most materials), it is obvious that its shape will be determined largely by the material used in the lining. If lumber is used, the square or rectangular shape is best, but if it be lined with brick, concrete, or rubble masonry, less material will be used and a stronger curb will result from the adoption of a circular section. The dimensions of the pit will be determined largely by the dimensions of the pump to be used, but in no case should it be less than 6 feet in diameter or on a side. For depths less than 30 feet in firm material, the pit may be dug and afterwards lined or curbed, but for greater depths the danger of caving should necessitate either the use of a temporary lining or a permanent lining which sinks as excavation progresses and is constantly built upon at the top. In the digging of the pit the use of a well-machine will be found convenient to facilitate the removal of material excavated and for lowering shoring

material, timbers, and curb material, etc., in the pit during construction.

Practice is divided on the question of whether it is more economical to drive the pipe from the bottom of the pit or to continue the pipe to the ground surface and drive from

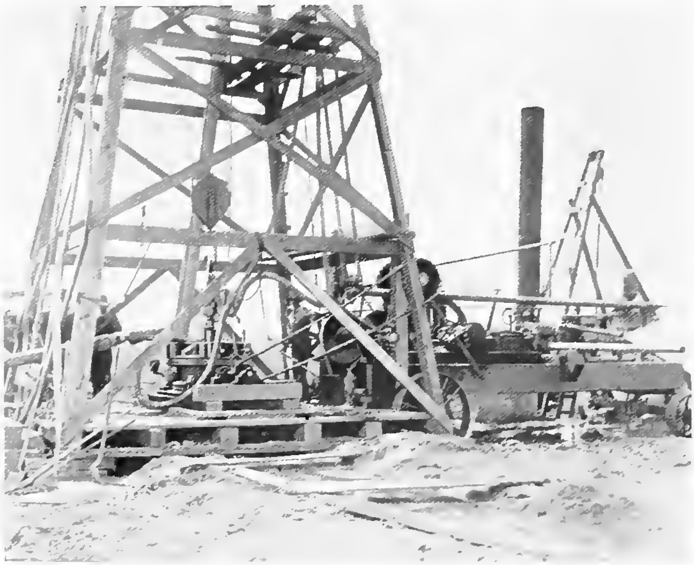


FIG. 11.—A rotary drilling rig in operation in Texas. An unusually rapid means of drilling large wells in alluvial formation. Has drilled 30-inch wells 250 feet deep in 8 days, including setting-up and disassembling of rig, no rock being encountered.

that level. In the latter case an extra length of pipe equal to the depth of the pit must be furnished, but there is the advantage of the greater weight on the driving shoe when the pipe must be driven, and also when it becomes necessary to turn it (as frequently happens even in churn drilling) it is a much easier operation when the pipe extends above ground level. Of course in rotary drilling the pipe must of necessity extend to or above ground level.

Weights of Pipe.—In the matter of purchase of pipe it is well to have in mind the fact that wrought-iron or steel piping is made in several weights. What is known as standard or merchant weight pipe is the common weight. There is

TABLE VI

STANDARD STEAM, GAS, AND WATER PIPE

Nominal Inside Diam. Inches	Actual Outside Diam.	Nominal Weight per Ft. Pounds	Threads per Inch	Nominal Outside Diam. Couplings
1/8	.40	.40	27	.562
1/4	.54	.42	18	.718
3/8	.675	.56	18	.875
1/2	.84	.84	14	1.000
3/4	1.05	1.12	14	1.312
1	1.315	1.67	11 1/2	1.625
1 1/4	1.66	2.24	11 1/2	1.937
1 1/2	1.9	2.68	11 1/2	2.125
2	2.375	3.61	8	2.750
2 1/2	2.875	5.74	8	3.250
3	3.5	7.54	8	3.812
3 1/2	4.	9.00	8	4.375
4	4.5	10.66	8	4.937
4 1/2	5.	12.49	8	5.406
5	5.563	14.50	8	6.031
6	6.625	18.76	8	7.406
7	7.625	23.27	8	8.250
8	8.625	28.18	8	9.187
9	9.625	33.70	8	10.50
10	10.75	40.00	8	11.68
11	12.	45.00	8	12.12
12	12.75	49.00	8	13.87

also a grade or weight known as artesian-well casing, which is much lighter for the same nominal size than standard pipe.

Standard pipe is always designated by its nominal inside diameter, and for the sake of consistency casing should be measured in the same way. It will be found, however,

that sizes 3-inch, 4-inch, and 5-inch may mean either inside or outside diameter; thus a 5-inch casing may mean one whose internal diameter is 4¾ inches and external diameter 5 inches, or one whose internal diameter is

TABLE VII

ARTESIAN WELL CASING

Nominal Inside Diameter	Actual Outside Diameter	Nominal Weight per Foot Pounds	Threads per Inch	Nominal Outside Diam. Couplings
2	2¼	2.22	14	2.69
2¼	2½	2.82	14	2.88
2½	2¾	3.13	14	3.19
2¾	3	3.45	14	3.50
3	3¼	4.10	14	3.78
3¼	3½	4.45	14	4.00
3½	3¾	4.78	14	4.25
3¾	4	5.56	14	4.63
4	4¼	6.00	14	4.69
4¼	4½	6.36	14	4.94
4½	4¾	6.73	14	5.22
4¾	5	7.80	14	5.56
5	5¼	8.20	14	5.78
5 3/16	5½	8.62	14	6.06
5⅝	6	10.46	14	6.63
6¼	6⅝	11.58	14	7.13
6⅝	7	12.34	14	7.69
7¼	7⅝	13.55	14	8.22
7⅝	8	15.41	11½	8.63
8¼	8⅝	16.07	11½	9.31
8⅝	9	17.60	11½	9.75
9⅝	10	21.90	11½	10.81

5 inches and external diameter is 5¼ inches. It is advisable, therefore, in ordering casing that the words "external diameter" or "internal diameter," as the case may be, follow the particular size desired. The above tables give the sizes and weights of standard piping and casing which will show

the distinction in sizes very clearly, as well as the comparative weights per foot for the same nominal sizes.

Tapering of Borings.—If a well has been started with standard pipe and after reaching a certain depth cannot be driven further because of friction, the boring is usually continued by dropping down inside the pipe a smaller-sized casing or pipe (usually the former), of such diameter that couplings on the inner pipe will allow it to pass freely but at the same time give a fairly close fit. Thus 8-inch standard pipe has an actual internal diameter of 7.98 inches so that 6⅝ inches (inside diameter) casing, the couplings of which are 7.69 inches outside diameter, will be able to enter the pipe without difficulty.

Special joints may be secured on piping such as "inserted joints," "flush joints," etc., the object of such joints being to make a smooth exterior surface and thus lessen the friction in driving which arises with piping having the usual coupling joints. Such special joints cost extra and since they are weaker than standard pipe couplings should not be used except in special cases. They can only be obtained on the larger sizes. Where a pipe is to be subjected to heavy driving, a special coupling joint can be obtained which by the use of specially long threaded ends and special couplings allows the ends of adjacent pipe sections to butt together, thus preventing threads being stripped and couplings split, as sometimes occurs during heavy driving with ordinary couplings. For very deep drilling, grades of pipe known as heavy or extra heavy should be used with special joints if the expense is not prohibitive.

As may be seen from the above tables, standard pipe weighs about double the artesian-well casing of the nearest equivalent nominal internal diameter, and it usually costs about one and one-half times as much as the casing. Where

the well is a great distance from a point of shipment the freight charges on casing will be very much less than on the same length of standard pipe, so that casing is much the cheaper delivered at the site of the well. It must be remembered, however, that casing cannot be driven, without great risk of injury, to a depth greater than 100 feet by "spudding," that because of its lighter weight it does not sink as readily as pipe, and it is much more easily injured in assembling. Another feature of importance, particularly in steel casing where the water is alkaline, is the ease with which electrolytic action causes serious holes to be eaten in the thinner casing, although, of course, it will only be a matter of somewhat longer time when standard pipe will be similarly injured. In such water the only safety consists in specifying and being sure one gets the purest kind of wrought-iron pipe.

Stovepipe Casing.—A method of well drilling familiar to Californians, but not much used outside of that state, is that known as the "stovepipe" method. It is used with considerable success in alluvial material, but cannot be recommended where coarse gravel or boulders are likely to be encountered. The casing consists of riveted steel sections built up in a double layer, the outer telescoping over the inner and breaking joints, thus making the riveting of adjoining sections unnecessary. A cutting section of heavier sheet steel is provided on the lower end, and the whole is sunk by ordinary spudding methods, except that the casing is forced downwards by hydraulic jacks. As a section is lowered, more of the stovepipe sections are added. Depths in excess of 1,000 feet have been attained by this method. The most interesting feature of the method is that by means of a special cutting tool lowered inside the casing upon completion of the well, vertical slits are cut in the casing opposite those strata which the driller's log indicates are

water-bearing, thus solving the question of a strainer, and insuring that the strainer will be exactly where wanted. It is not unlikely that this same idea might be applied successfully to the perforation of artesian-well casing which would not be very much more difficult to cut than two layers of No. 12 sheet steel, particularly in the larger sizes of casing. It may be added that the "stovepipe method" is not used for borings less than 12 inches in diameter, the most common size being 14 inches.

CHAPTER VI

PUMPS AND PUMPING MACHINERY AND APPLIANCES

In the foregoing chapters we have discussed methods of arriving at an approximate estimate of the amount of water required, we have discussed the possibility of estimating the probable capacities of wells, when the supply must be taken from an underground source, and we have given, somewhat briefly and possibly inadequately, an idea of the method by which the well may be constructed and the water supply developed. In the present chapter and one or two following, we shall describe the pumping machinery which it is advisable or necessary to use to bring the supply to the surface or to pump it from the source to the point at which it is desired the water shall be used.

Caution Needed in the Selection of Pumps.—At the outset we desire to sound a note of warning and caution to those who feel themselves competent to select and install their own machinery. Nothing is more commonplace than a pump, and probably every American who has had any experience with one, no matter what the type, has an inward conviction that he could invent a better one, the natural result being that inventive geniuses by the score have invented and patented pumps,—while occasionally some inventor more courageous or fortunate than the rest succeeds in getting his ideas into concrete form and on the market. The curious thing about all such devices is the absolute assurance of those interested in their introduction that they will surpass anything now on the market in efficiency, durability, and general excellence. It is no uncom-

mon thing for mechanical efficiencies of 95 per cent. to be claimed, and an enthusiastic salesman once informed the writer that he was sure 100 per cent. efficiency could be secured in the use of his pump if the water passages and pipes were nickel-plated to reduce the friction of water on iron. One needs reflect but a moment to appreciate the absurdity of such claims, for it is one of the elementary principles of physics that no machine can be 100 per cent. efficient, while any one familiar with the ordinary processes of manufacture will realize that even relatively moderate efficiencies in machinery can only be attained by refinements in design, materials, and manufacture which are only warranted when the saving of power incident to the use of the very efficient machine will pay interest on the difference in cost between it and one of less efficiency. Other important considerations which would justify or condemn the use of the highly efficient machine are convenience in installation and use, durability, space occupied, weight, etc.

Pumps which have been Proposed.—Among the many pumps which at one time or another have been brought forward by hopeful geniuses for the solution of the problem of irrigation pumping are: Screw pumps, propeller pumps, bucket elevators, air lifts, air displacement pumps, and various modifications of centrifugal and turbine pumps, rotary pumps, balanced plunger pumps, etc. The last named was conceived by an inventor who effected by means of weights on the end of a lever a balancing of the column of water on top of the pump plunger, so that according to his idea it would require no more power to pump a given quantity of water through 500-foot head than through 50 feet. All of these pumps will actually pump water, and many of them have some merit, but the great majority are found by mechanical test to fall far below the expectations of their inventors, while many are extremely

wasteful of power and have efficiencies of from 25 to 50 per cent. Such pumps waste much of the power applied to them in shock and churning effects of the water, besides purely mechanical defects causing friction and eddy losses.

It rarely pays, therefore, for the man who desires an efficient, serviceable, and satisfactory pumping plant to be led aside and induced to purchase some recently devised and comparatively untried pumping device, whose manufacturer attempts to catch the unwary by attractive guarantees of low cost of pumping. Before being induced to purchase such machinery the intending purchaser would do well to demand a mechanical test of the pump and a report upon the same made by a competent and reliable mechanical engineer whose position and reputation enable him to give an unbiased opinion.*

What Should Decide the Make and Type of Pump to Use? —A decision as to the type of pump to adopt for a particular set of conditions should be governed somewhat by its reputation. The standard pumps now on the market have been slowly evolved through years of experience and experimentation on the part of skilled designers who apply the

* It is indeed surprising, not only how quickly the news of a new device spreads, but how eager Western people are to apply every advance in the art of pumping to the problem of cheap irrigation pumping. The writer was surprised, recently, to receive a letter from a gentleman in Utah asking the opinion of the writer as to whether, in his judgment, the Humphrey Gas Pump could be used with success in the irrigation of his farm of about 100 acres. The writer was compelled to reply that, however interesting and successful the Humphrey pump might be, it seems scarcely possible in the present stage of its development to adapt it successfully to the uses of an irrigation pump on a comparatively small farm in a region remote from coal suitable for the production of producer gas. We have no doubt, however, that eventually this pump or one acting on the same principle will, when made in the right sizes, be of value in the solution of the question of cheap water supply for moderate lifts.

results of experience in years of practical operation to the design and construction of their pumps. It is true, of course, particularly in the case of centrifugal pumps, that there are stock sizes which are sold, like shelf hardware, with only the most meagre attention to the particular conditions under which they are to operate. Even in such cases, however, the purchaser may be sure, if the pump is made by a reliable manufacturer, that it will be durable and serviceable, which assurance is lacking in the case of many of the so-called "freak" pumps already described. The writer must not be considered as decrying or discouraging originality in pump design, but the pumping-plant operator whose profits depend upon the reliability and durability of his equipment can better afford to adopt and use standard machinery than act as an experimental agent for some new and comparatively untried device. The expense of experiments and the burden of failures had much better be borne by those engaged in its manufacture than by the purchaser, whose livelihood is likely to depend upon its successful operation. If a purchaser desires the high economy and efficiency usually claimed by promoters of new styles of pumps, he can secure the same or higher economy in more refined machinery, for which, however, he will be required to pay a correspondingly higher price.

The fact that a pump will actually raise water is no guarantee of its efficiency, that pump being most efficient which raises a given quantity of water through a given head with a minimum power consumption. Until a new pump can be shown by reliable and thorough mechanical tests to exceed the efficiency of standard machinery, it should be let alone by the irrigation farmer, unless conclusive evidence can be produced that it is more reliable, more durable, and very much lower in first cost than a standard machine which will do the same work with the same power consumption.

The Standard Types of Irrigation Pumps.—There are three standard types of pump which Western practice has shown are suitable for irrigation work. These are centrifugal pumps or turbine pumps (which are a special form of centrifugal), single or multi-cylinder reciprocating pumps, and well cylinders. In rice irrigation certain forms of rotary pumps have been used with such success that they might properly be called standard equipment. Under certain special conditions a water-lift or bucket-and-chain pump might also be included.

Each of these types of pumps is best adapted to a certain set of conditions, the limits of which are very well recognized, though unquestionably the limits which we shall hereinafter mention will be called in question by those manufacturers who make but one type of pump and who profess to believe this type suitable for any set of conditions without regard to economy of operation, capacity, head, or practical difficulties of operation.

CHAPTER VII

CENTRIFUGAL PUMPS

The centrifugal type of pump enjoys a well-deserved popularity with those who have to solve the problems of irrigation pumping, because of its extreme simplicity, its low price, the comparative ease with which it may be installed, and its freedom from some of the annoyances which are encountered in the operation of other types. It is, however, in the small and stock sizes a machine of low efficiency, as will presently be pointed out, and for that reason, where the cost of power is an important consideration, it may be well to study its characteristics with some care before choosing it for any given case.

The Centrifugal Pump Described.—In its simplest form, the centrifugal pump comprises a casing, D, inside of which

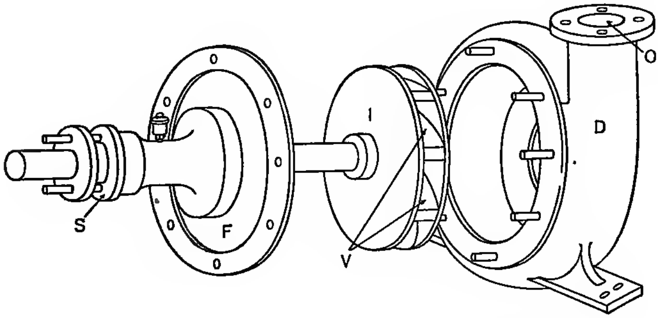


Fig. 12.—The parts of a simple, cheap centrifugal pump.

is rotated a runner or impeller. The impeller, I, as shown in the figure has side plates between which are cast backwardly bending vanes V. the water entering the impeller

through an opening at the centre on the far side of the impeller (not shown in the sketch) and being ejected at high velocity from the openings around the periphery of the impeller, thence passing through the flanged outlet O into the discharge pipe. The diameter of the opening O determines the nominal size of the pump. Thus in a 6-inch pump, the opening O is approximately 6 inches in diameter. In the cheek plate F is usually a babbitted bearing to support the shaft of impeller and a stuffing box S by which air is prevented from entering the pump and destroying the vacuum. To the left of the parts shown would be a pulley mounted on the shaft (if the machine be belt-driven) and an outboard bearing. There is also usually a thrust bearing provided at or near the outer end of the shaft to take up any unbalanced thrust due to the action of the water on the blades of the impeller as it enters the latter. The form of pump shown in the sketch is called the horizontal type; those in which the shaft is vertical belong to the vertical type, and each has its proper sphere of usefulness, depending upon location, as hereinafter explained. The type of impeller shown is called the closed type, but some excellent makes of pumps have what is termed the open type as shown in Fig. 21.

The relative advantage of the two types of impellers is not well determined, although it is to be noted that all of those pumps in which a determined effort is made by the designers to secure a higher efficiency than is obtained in the ordinary centrifugal pump have enclosed impellers with carefully moulded and shaped water passages. For total heads or lifts in excess of 75 or 100 feet the speed at which the simple centrifugal pump must be run becomes so excessively high that two or more simple pumps must be operated in series; that is, the discharge of one pump is led to the suction of the next, and thence into the

discharge pipe. The quantity of water obtained by such a combination is about the same as that from a single pump and the head through which water may be lifted for a given speed of rotation is roughly as many times that for a single pump as there are stages, thus in a two-stage pump the head attainable would be about twice that in a single-stage pump. Multi-stage pumps may be built as two or more separate simple pumps connected together by suitable piping and run by the same shaft or there may be a number of runners in the same casing with suitably shaped passages to convey the water from around the periphery of one impeller to the centre of the next. Such pumps, be-

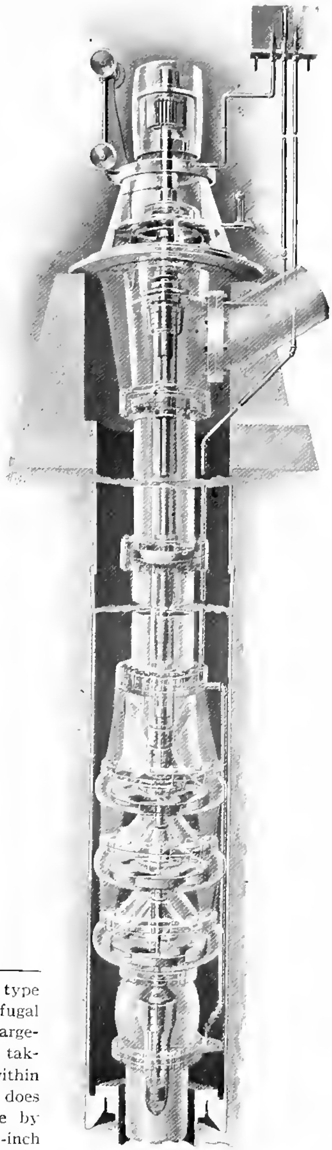


FIG. 13.

FIG. 13.—Phantom view of a special type of belt-driven multi-stage vertical centrifugal pump arranged to be lowered inside a large-sized casing sunk by rotary methods, and taking water from a driven well of depth within 200 feet. Is entirely self-contained and does away with open pit. A later type, made by same manufacturer, may be installed in 12-inch casing and has delivered 1,000 G.P.M.

cause of the complexity of the patterns from which they are made and the complex cores and difficult castings involved are somewhat more expensive than the combinations of simple pumps. In following pages are views of

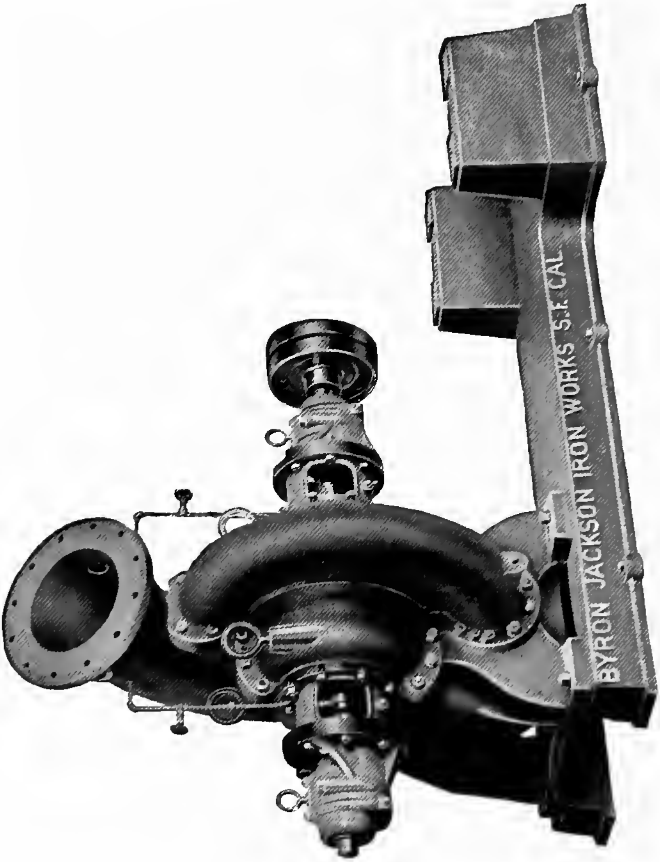


Fig. 14.—An excellent design of large single-stage pump, adapted for pumping from open water source. Flow lines are designed for vertical suction and overhead discharge with minimum change in direction of flow. Note the splendid design of split case which may be removed (allowing inspection of impeller, removal of trash, etc.), and be replaced in less than one hour. This pump has bronze impeller, bronze sleeves on shaft in stuffing boxes, water seal, ring oiling bearings, double suction.

horizontal simple and multi-stage, as well as of the vertical types.

Specifications for Centrifugal Pumps.—For the ordinary

small individual installation, it is idle, perhaps, to suggest specifications which should govern the purchase of pumps, for several reasons: First, the average individual buys upon the reputation of a pump or upon its durability and serviceability in some instance which has come under his direct observation, frequently regardless of mechanical details or efficiency; second, the pump he buys is usually of such size that it comes within the range of stock sizes and it would be very difficult and expensive to secure a single machine embracing other than the usual stock details. Except, therefore, in cases where a large number of small pumps are bought at one order for some co-ordinated scheme of pumping it is useless to attempt to frame specifications to which pump builders may be expected to care to conform. It may, however, not be out of place to enumerate certain essential features which an efficient and durable centrifugal pump should comprise even in comparatively small sizes and which should govern the selection and purchase of machinery for any but the cheapest central station plants.

Pump Case.—To be of close-grained cast-iron, free from blow-holes and shrinkage cracks. Should be suitably reinforced with ribs and flanges in sizes over 6 inches and with discharge heads greater than 75 feet. The pump case should be divided through the centre line of the shaft in a plane affording the greatest ease of removal of half of case, to permit inspection and cleaning of interior of case and of impeller, without disturbance to the suction or discharge piping or connections. This is of special importance in the case of pumps taking water from a canal or river where weeds, fish, and trash of all kinds may be taken in with the water through the suction pipe and cause serious clogging and interference with operation of pump. With solid-case pumps the job of taking apart a

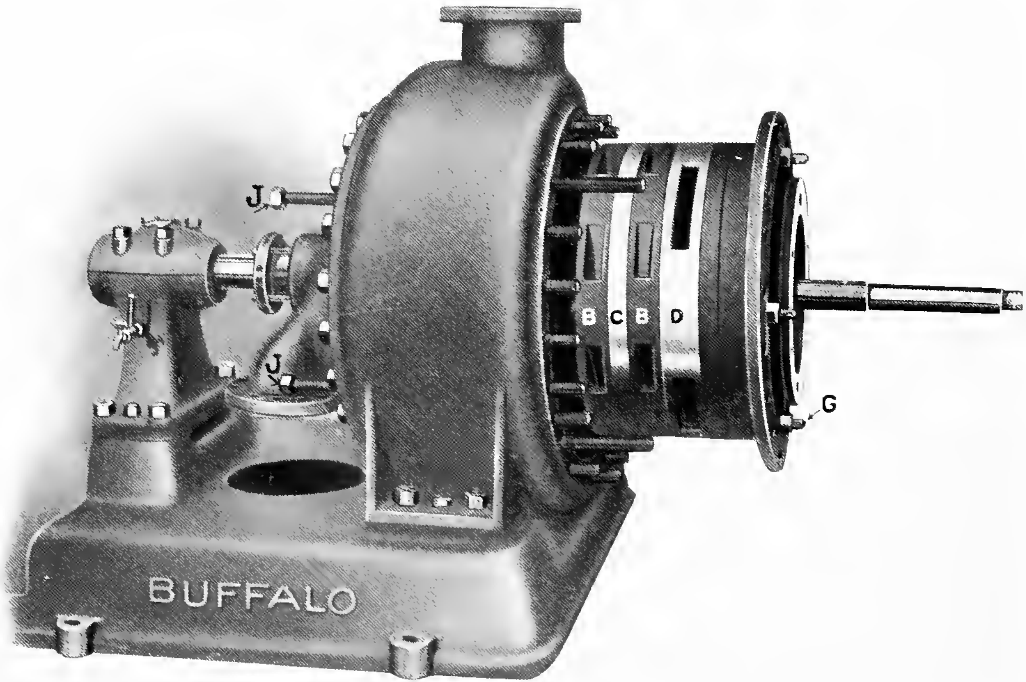


Fig. 15.—A multi-stage centrifugal pump partly dis-assembled to show diffusion vanes and a portion of impeller.

pump to clean and inspect it, is one involving much time and labor. With split-case pumps this is comparatively simple.

Suction.—For all except very small sizes, the suction opening of single-stage pumps should be double, allowing water to enter impeller from both sides. This avoids end thrust as with side suction pumps, in which it must be resisted by thrust bearings and is a constant source of power loss in spite of the various hydraulic balancing arrangements in use. The suction passage should be of ample size with gradually curving flow lines and be self-contained within the case.

Impeller.—For large pumps this should be of bronze, preferably of the composition known as Government Bronze. This is resistant to corrosion and under the scouring action of water acquires a smooth surface which greatly reduces the energy loss in friction of water passing at high velocity through the impeller.

Packing Joint and Clearance.—The clearance between the pump case and impeller at the packing joint should be a running fit and at this joint preferably should be bronze rings that may be replaced when worn. In the more elaborate pumps a labyrinth packing is sometimes introduced at this point.

Shaft.—The shaft should be of forged, open-hearth steel and of ample strength to resist torsion, bending, and other stresses. Where it passes through the stuffing box or boxes and on the inside of the pump case it should be protected from wear by a removable bronze sleeve.

Stuffing Boxes.—These should be arranged for water seal and soft packing and the glands should be of bronze. In the larger pumps glands should be split to facilitate complete removal without disturbing other parts.

Bearings.—In the bearings only the best grade of babbit should be used. In horizontal pumps the babbit

should be in split shells, which may be removed without disturbing other parts. The bearings should be ring oiling with ample oil reservoir provided with glass oil-gauge. The bearing pedestal construction should be rigid, and so formed as to prevent throwing of oil. Ample thrust collars should be provided in all horizontal double-suction pumps to take up any slight unbalancing due to clogging of one side of impeller. For side suction, single-stage pumps of large size the thrust bearing should be of marine type and provided with water jackets. In vertical pumps a ball- or roller-bearing of ample size should be provided to carry full weight of shafting, impeller, and also motor armature, in electrically driven types, in addition to any unbalanced thrust due to water pressure.

Flexible Couplings.—These should always be provided between motor and pump in direct-connected units, to eliminate wear on bearings due to slight inaccuracies in alignment.

Inspection and Tests.—For a large pumping-plant project careful specifications covering points above enumerated should always be drawn up by a competent mechanical engineer and the contract should permit inspection of the machinery during construction, to see that mechanical details are built according to specifications. Finally, it should be stipulated that the pump or pumps should be tested at the factory previous to delivery under the conditions of speed and head at which they are to operate and, if possible in the case of electric drive, should be tested with the same motors by which they are to be operated. The results of the test should be plotted on cross-section paper and curves drawn showing the characteristics of the pump. These curves should be considered as guarantee of performance and should be checked by test under running conditions subsequent to completion of plant.

Characteristics of Centrifugal Pumps.—Those who now operate, as well as those who expect to operate centrifugal pumps should have some familiarity with the mechanical characteristics of such machinery, for it is undoubtedly true that much of the dissatisfaction we find among those who use these pumps has been due to an attempt to operate them under conditions for which they were not designed or well adapted. As will be noted from the brief description already given, the centrifugal pump differs from a reciprocating pump, with which most of us are familiar, in having no piston or plunger and no valves. Its action evidently, therefore, depends upon the whirling motion imparted to the water by the rapidly-rotating impeller. Simple as this action may seem, the fact remains that although many voluminous works have been written upon the subject and many, and sometimes conflicting, theories advanced, no formula or method has yet been devised by which, with the speed of the impeller and the size and proportions of the impeller and casing given, it is possible to figure the capacity of a pump or its efficiency. What is known definitely of the action of centrifugal pumps has been determined almost entirely by experiment and in designing a new pump to give certain desired characteristics, the designer is helped but very little by theory, and must project largely his knowledge of the action of existing pumps to the new design. By this process of evolution, centrifugal pumps are continually being improved upon and higher efficiencies attained, but even in those of most advanced design there occur obscure losses in energy due to friction, shock, or impact, secondary whirling effects or eddies and leakage of water through clearance spaces which materially cut down the mechanical efficiency of the machine and either entirely upset the theoretical notions which attempt to explain its action, or by reason of their obscurity make the constants impossible

of determination in any formula in which these losses are recognized and allowed for.

What the Plant Designer or Operator Must Know.—So far as the operator of a centrifugal pumping plant is concerned, and particularly the man designing such a plant or intending to use centrifugal pumps, he is interested not so much in questions of the design of the pumps themselves as in what the pumps that he can buy will do under a given set of conditions. Unfortunately he is not greatly assisted in securing such knowledge by the information which may be gleaned from a manufacturer's catalogue containing descriptions and ratings of their stock pumps. What a purchaser desires to know is what speed is required to force water through a given head, what discharge may be expected at that head, and what actual horse-power is required under those conditions to operate the pump. The manufacturers' rating as given for a particular size of pump is usually what is known as "the economic capacity," which is a term of doubtful meaning and of very little use to a pump purchaser, for nothing is usually said as to whether this capacity is the maximum attainable, which may be at high speed and low head or is that capacity which is secured under conditions of maximum efficiency. It is the peculiar characteristic of centrifugal pumps that the capacity is a variable depending upon the speed at which it is run, and the total head against which it operates. Conversely, every centrifugal pump when run at a certain speed will give a certain discharge at a certain head. If the speed be increased with the head constant, the discharge will be increased according to a definite law, and if the speed be maintained constant and the head be decreased, the discharge will generally increase. Furthermore, every centrifugal pump has a definite head for different speeds at which it operates most economically from the standpoint

of power consumption and in order to force the water through this head this particular speed should be used, if, as is frequently the case, the cost of power is the most important factor in the cost of operation.

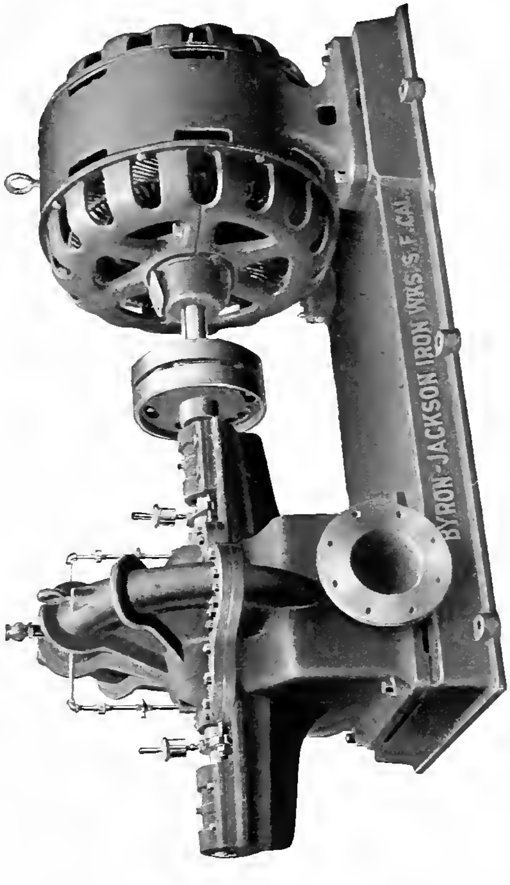


FIG. 16.—A first-class type of **single-stage**, double suction, horizontally split case pump with substantial bearings, water seal, bronze sleeve on shaft in stuffing-boxes, and good workmanship throughout. Suited for pumping from river or canal to lifts **of not over 100 feet**. Suction and discharge are horizontal.

The Efficiency of the Pump.—The efficiency of a centrifugal pump, as of every other pump or any mechanical contrivance transforming mechanical work into another form

of energy, is the ratio of the effect to the cause, or in the case of a pump we may define it as:

$$\text{Efficiency} = \frac{\text{Energy in moving water}}{\text{Energy supplied pump.}}$$

The energy in the moving water is the product of the weight of water elevated in a given time multiplied by the

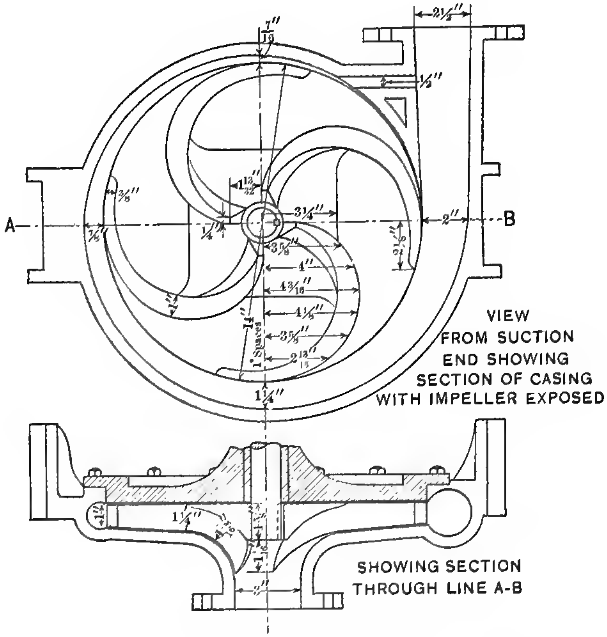


FIG. 17.—Cross-sections of 2½-inch Pump, Serial No. 1. (See Diagram 5.)

total head in feet through which the water is raised. Thus a pump elevating continuously 450 gallons of water per minute through a total head of 8.8 feet gives energy to the water equivalent to one horse-power or 33,000 feet-pounds per minute. If the motor or engine by which the pump is run delivers two horse-power to such a pump the efficiency

will be 50 per cent. and one-half of the power delivered by the engine will be lost in useless churning and fluid friction effects in the pump and by mechanical friction in its bearings and stuffing box. Just as the capacity of a

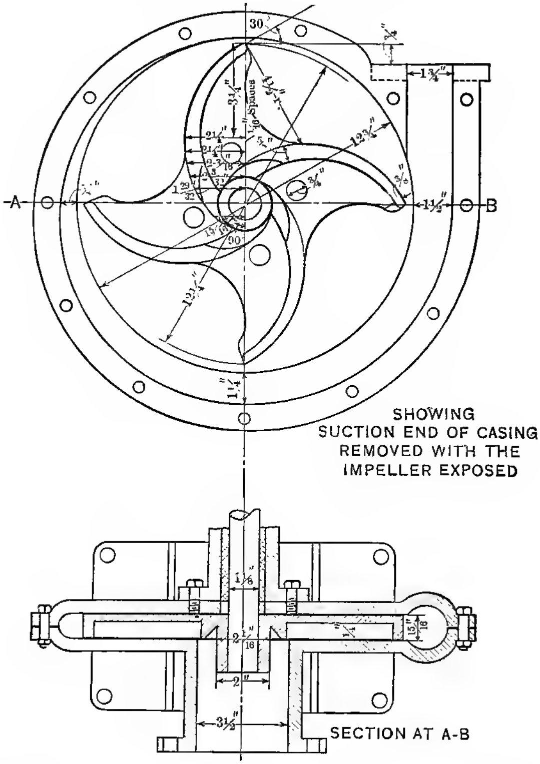


Fig. 18.—Cross-sections of 2-inch Pump, Serial No. 2. (See Diagram 6.)

centrifugal pump is a variable, so also is the efficiency, and for different heads and capacities we have different efficiencies, all varying according to certain laws. For any given speed there will be a certain head at which the efficiency will be a maximum, and a knowledge of these facts is

necessary to intelligent selection of a pump for a given purpose and to insure efficient operation after it is installed.

Pump Curves.—In the following pages are given a number of diagrams which show the characteristics of sev-

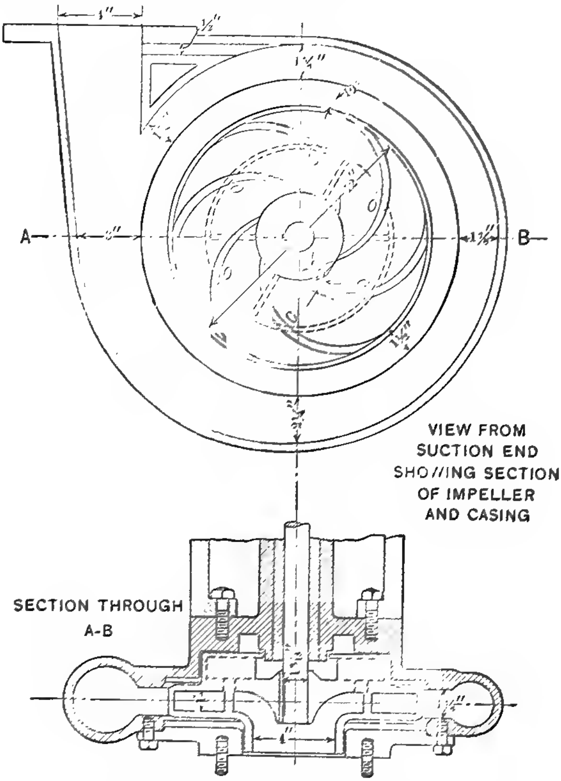


Fig. 19.—Cross-sections of 4-inch Pump, Serial No. 3. (See Diagram 7.)

eral pumps in a series of tests made under the direction of the writer in an investigation to determine various facts relative to the performance of stock sizes of centrifugal pumps such as are commonly used in irrigation work.

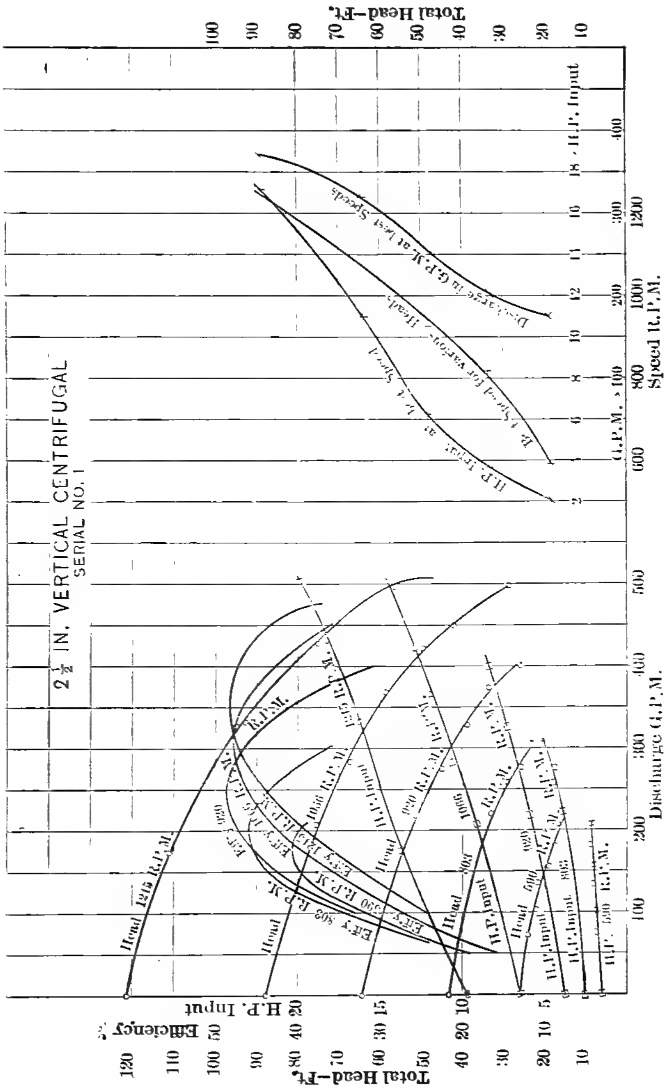

2½ IN. VERTICAL CENTRIFUGAL
SERIAL NO. 1
Total Head—Ft.
Efficiency %
H.P. Input
Discharge G.P.M.
Speed R.P.M.
G.P.M. × 100
H.P. Input
Discharge in G.P.M. at best Speeds
R.P.M. Speed for various Heads
H.P. Input at best Speeds

DIAGRAM 5

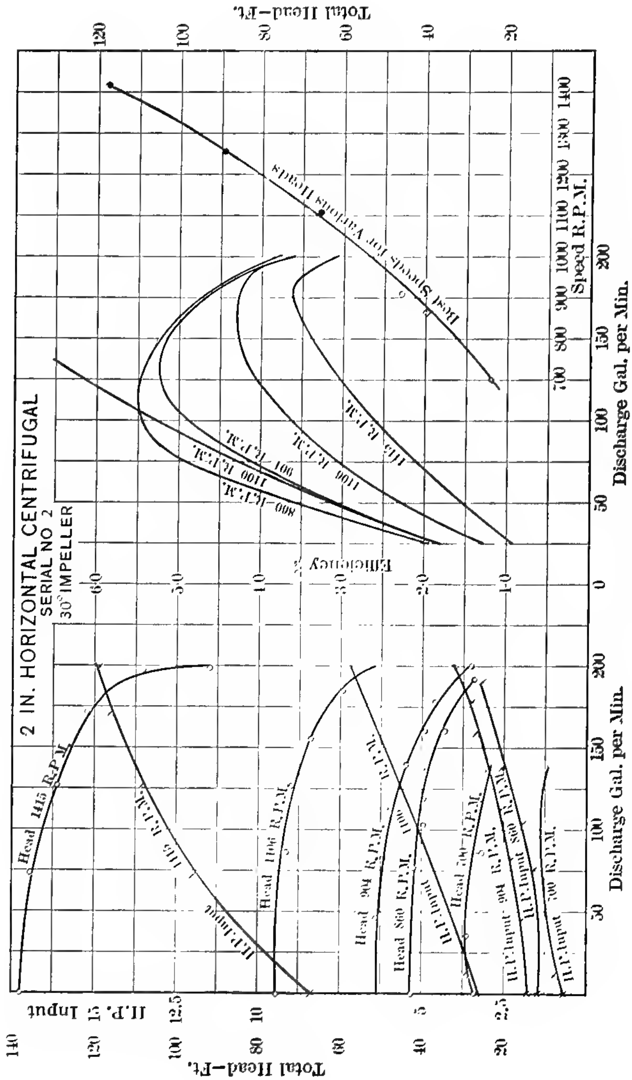

2 IN. HORIZONTAL CENTRIFUGAL
SERIAL NO 2
30° IMPELLER
Total Head–Ft.
H.P. Input
Discharge Gal. per Min.
Speed R.P.M.
Efficiency %
Best Speeds for Various Heads
Head 1415 R.P.M.
Head 1106 R.P.M.
Head 904 R.P.M.
Head 800 R.P.M.
Head 700 R.P.M.
H.P. Input

DIAGRAM 6

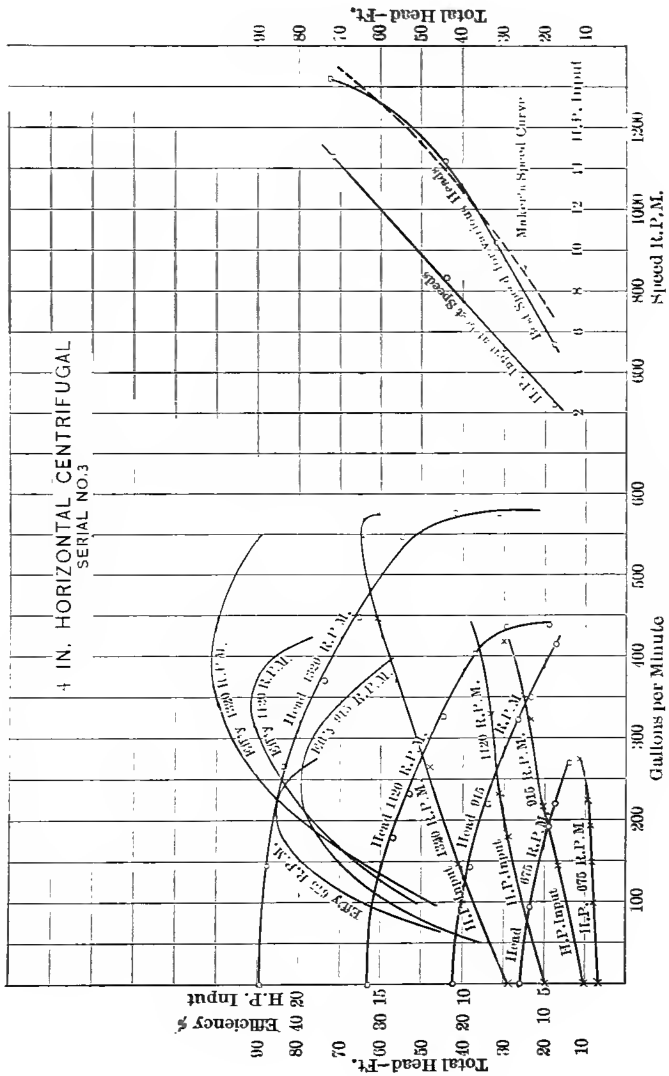

4 IN. HORIZONTAL CENTRIFUGAL
SERIAL NO.3
Total Head–Ft.
Efficiency %
H.P. Input
Gallons per Minute
Speed R.P.M.
Maker's Speed Curve
H.P. Input at Various Speeds
Best Speed for Various Heads

DIAGRAM 7

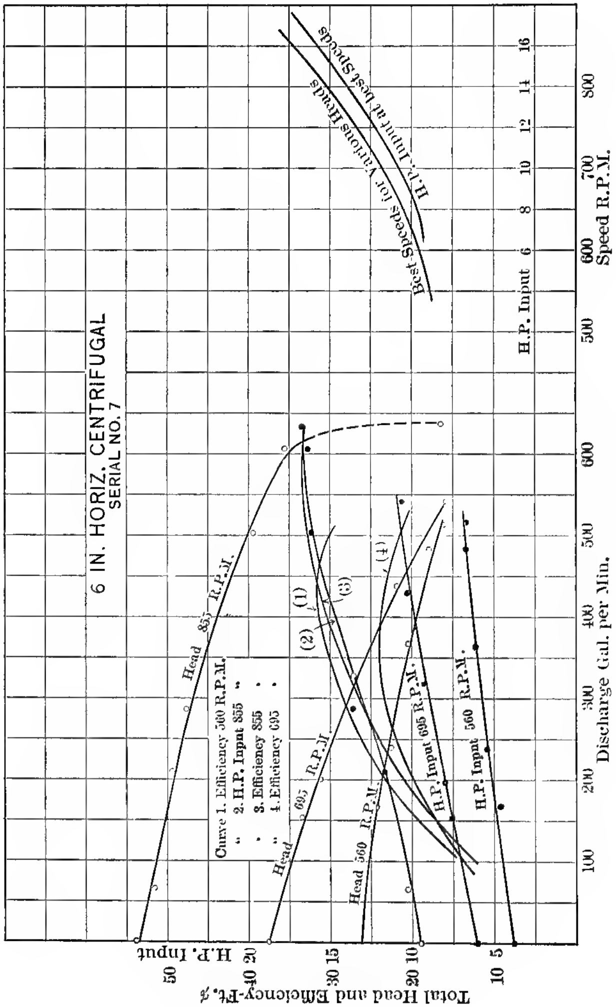

6 IN. HORIZ. CENTRIFUGAL
SERIAL NO. 7
Curve 1. Efficiency 560 R.P.M.
" 2. H.P. Input 855 "
" 3. Efficiency 855 "
" 4. Efficiency 695 "
Head 855 R.P.M.
Head 695 R.P.M.
Head 560 R.P.M.
H.P. Input 695 R.P.M.
H.P. Input 560 R.P.M.
Best Speeds for Various Heads
H.P. Input at best Speeds
(1)
(2)
(3)
(4)
H.P. Input 6 8 10 12 14 16
600 700 800
Speed R.P.M.
100 200 300 400 500 600
Discharge Gal. per Min.
H.P. Input
50 20
40 20
30 15
20 10
10 5
Total Head and Efficiency-Ft. %

DIAGRAM 8

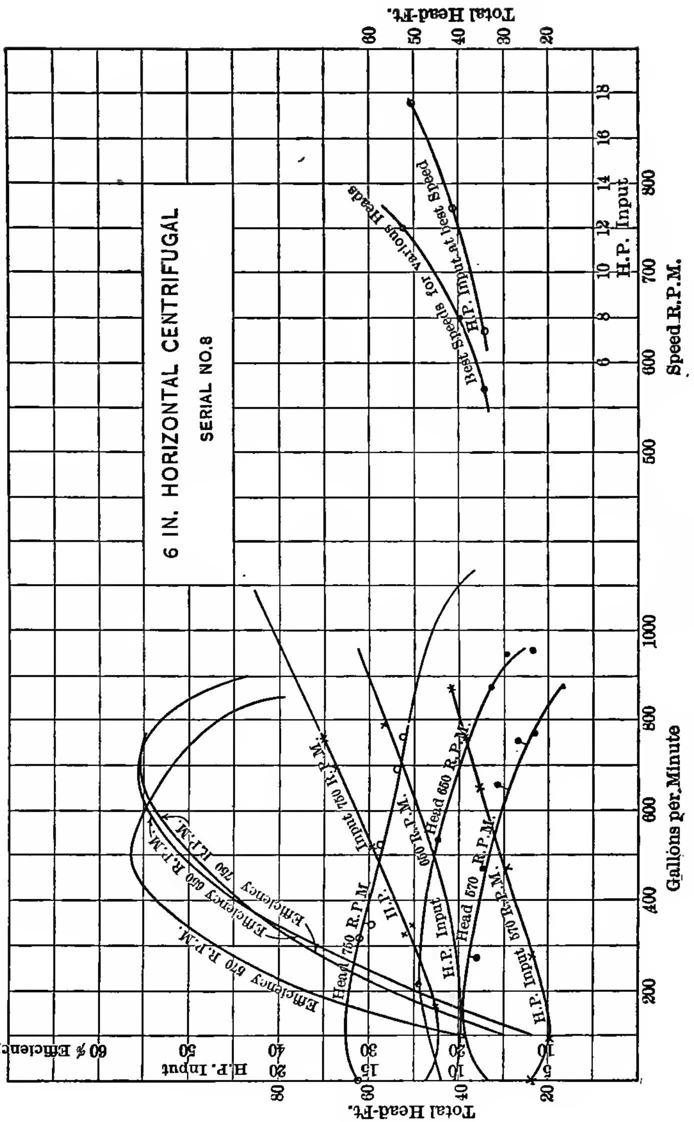
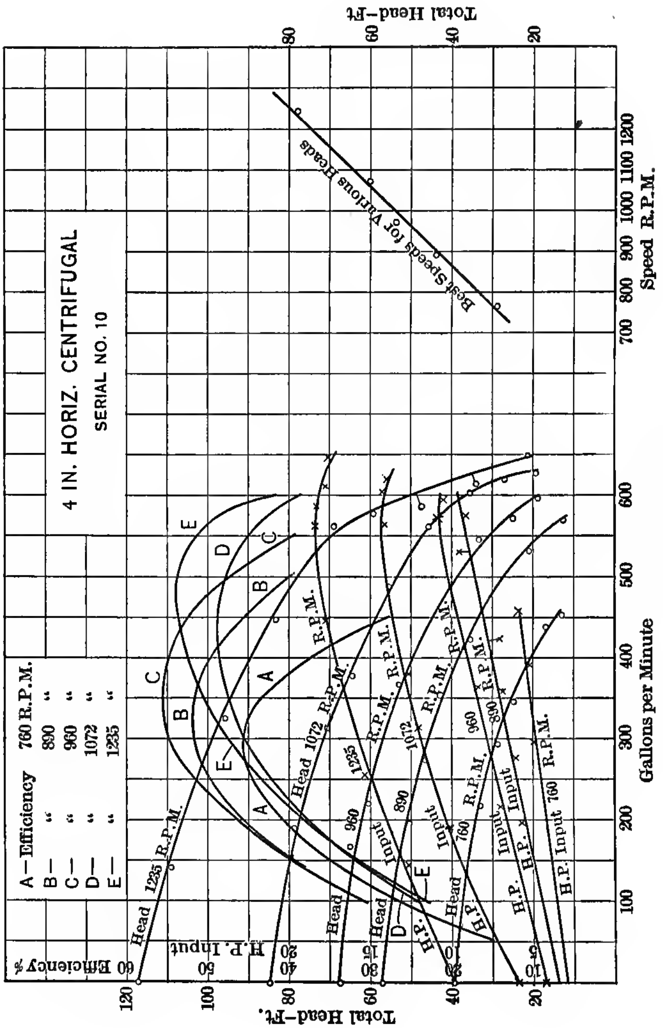

6 IN. HORIZONTAL CENTRIFUGAL
SERIAL NO. 8
Total Head-Ft.
H.P. Input
60 % Efficiency
Speed R.P.M.
Gallons per Minute
Best Speeds for various Heads
H.P. Input at best Speed
Efficiency 750 R.P.M.
Efficiency 650 R.P.M.
Efficiency 670 R.P.M.
Head 750 R.P.M.
Head 650 R.P.M.
Head 670 R.P.M.
H.P. Input 750 R.P.M.
H.P. Input 650 R.P.M.
H.P. Input 670 R.P.M.

DIAGRAM 9



4 IN. HORIZ. CENTRIFUGAL
SERIAL NO. 10
A—Efficiency 760 R.P.M.
B— " 890 "
C— " 960 "
D— " 1072 "
E— " 1235 "
Best Speeds for Various Heads
Total Head–Ft.
Efficiency %
H.P. Input
Gallons per Minute
Speed R.P.M.
Head 1235 R.P.M.
Head 1072 R.P.M.
H.P. Input 760 R.P.M.

DIAGRAM 10

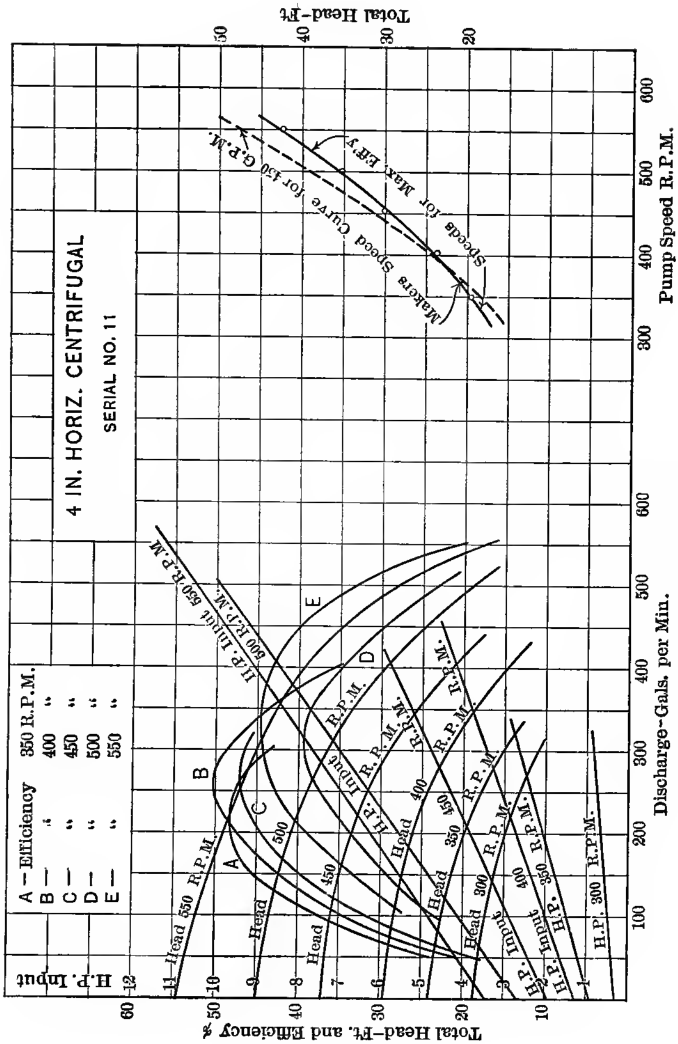

4 IN. HORIZ. CENTRIFUGAL
SERIAL NO. 11
A – Efficiency 350 R.P.M.
B – " 400 "
C – " 450 "
D – " 500 "
E – " 550 "
Total Head-Ft.
Pump Speed R.P.M.
Speeds for Max. Eff'y
Makers Speed Curve for 150 G.P.M.
H.P. Input
Total Head-Ft. and Efficiency %
Discharge-Gals. per Min.

DIAGRAM 11

The preceding diagrams give the following information: (1) The discharge in gallons per minute for various speeds when total heads are given. (2) The mechanical efficiencies

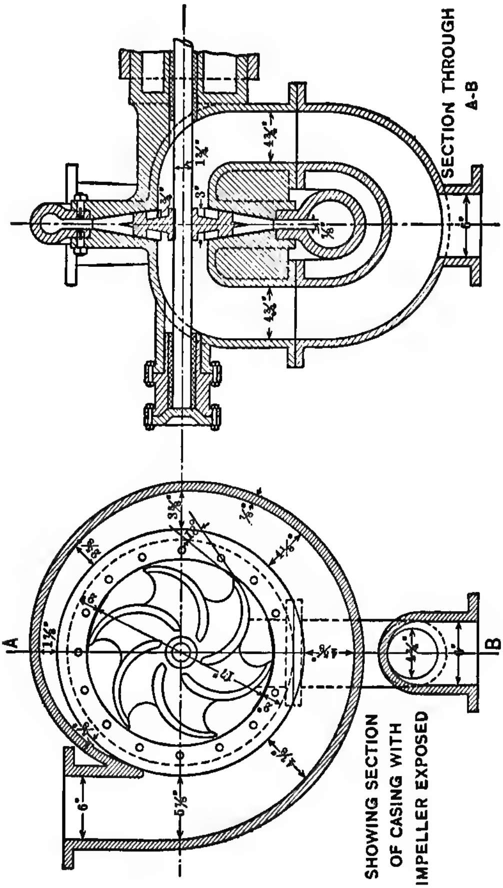


FIG. 20.—Cross-sections of 6-inch Pump, Serial No. 7. (See Diagram 8.)

at different speeds. (3) The horse-power required to be delivered to the pump in order that different quantities per minute may be discharged through different total

heads. Some of the diagrams also give the speeds which should be used to give maximum efficiencies at

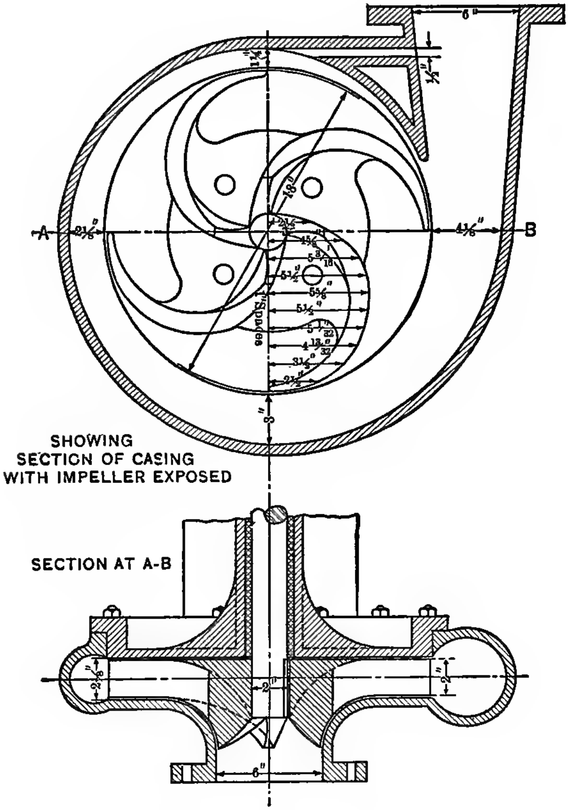


FIG. 21.—Cross-sections of 6-inch Pump, Serial No. 8. (See Diagram 9.)

different total heads and the corresponding horse-power input.*

* The names of the makers of the pumps corresponding to the diagrams are withheld for obvious reasons.

The Selection of a Pump.—To make use of the diagrams, let us assume that it is desired to pump a supply of 300 gallons per minute from a well in which water stands 30 feet below the surface, and in which the draw-down will not

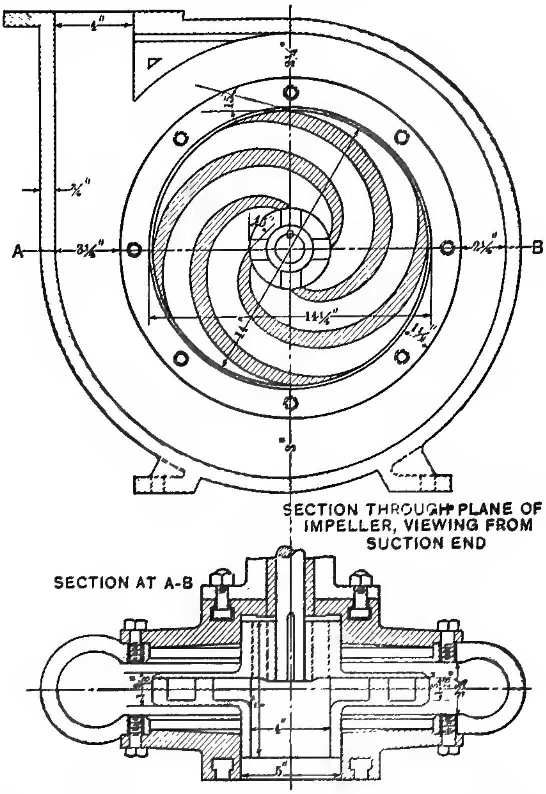


FIG. 22.—Cross-sections of 4-inch Pump, Serial No. 10. (See Diagram 10.)

exceed 15 feet at this discharge, making the total hydrostatic head at this discharge about 45 feet. In the following figure, Fig. 23, is illustrated the meaning of the terms relating to "head" or "lift."

As will be apparent from the figure, the total distance through which the water must be elevated, or the hydrostatic head, is the distance of standing water below the level of water at the outlet, plus the "draw-down"; and the

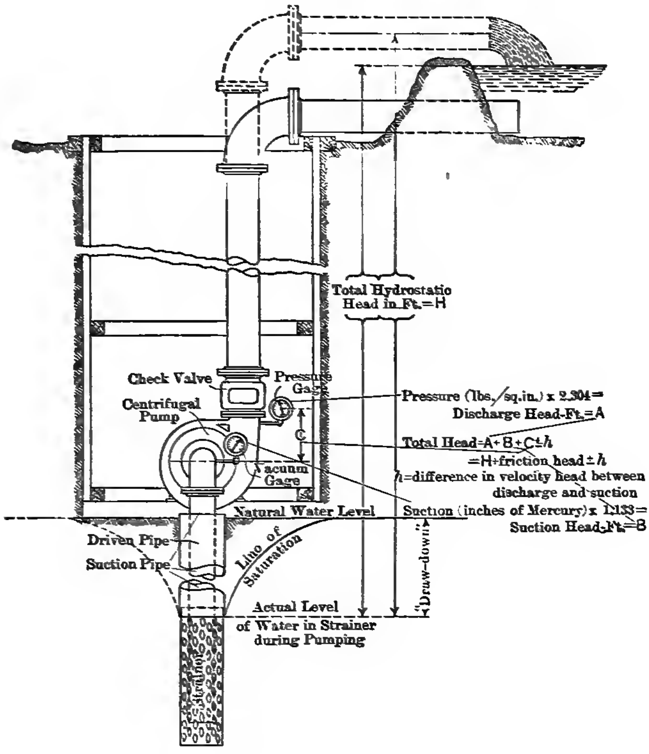


FIG. 23.

total head, which has the same meaning as the term used in the pump curve diagrams, is the hydrostatic head, plus the friction head, plus or minus a small correction called the difference in velocity head. The hydrostatic head may be determined from a knowledge of the depth of water below

the surface and the assumed "draw-down," but the friction head must be calculated in those cases where it cannot be allowed for in the reading of a pressure gauge. Thus as shown in Fig. 23, if a pressure gauge and a vacuum gauge be attached to a pump at the points as shown, the readings of these gauges, multiplied respectively by the proper constants as indicated in figure, give the total head in feet, when to the sum is added the vertical distance between the centre of the discharge gauge and the point of attachment of the vacuum gauge to the suction pipe (disregarding the correction for change in velocity head). Since, however, for a pump not yet installed, the gauge readings are not available, the total head must be calculated by adding to the hydrostatic head a correction for the friction head. It is important that this factor be allowed for, since it may in unusual cases amount to as much as the hydrostatic head. The friction head may be defined, for the benefit of those not familiar with the science of hydraulics, as that head which would be necessary in a perfectly level pipe-line to cause a flow through the pipe of the desired quantity of water. Thus, if it were desirable to cause a flow of 100 gallons per minute through a level pipe 2 inches in diameter and 100 feet long, this water would have to enter the pipe at one end through a large vertical riser at least 22 feet high in order that such discharge might occur. In other words, the friction head in a 100-foot length of pipe with a flow of 100 gallons per minute is about 22 feet. It is seen from this one example that friction head may be an extremely important item in the factors effecting flow of water in pipes, and in the design of pumping plants it must be reduced to a minimum, as will later be explained, by the use of pipes and fittings of proper size, in order that the cost of pumping may be reduced.

The hydrostatic head in the instance cited on page 86 was 45 feet. If the discharge be assumed to occur at the ground surface, the vertical length of pipe involved may be assumed to be the same as the hydrostatic head, and upon this assumption for the general case, Diagram 12 is figured, showing for various capacities and depths of wells

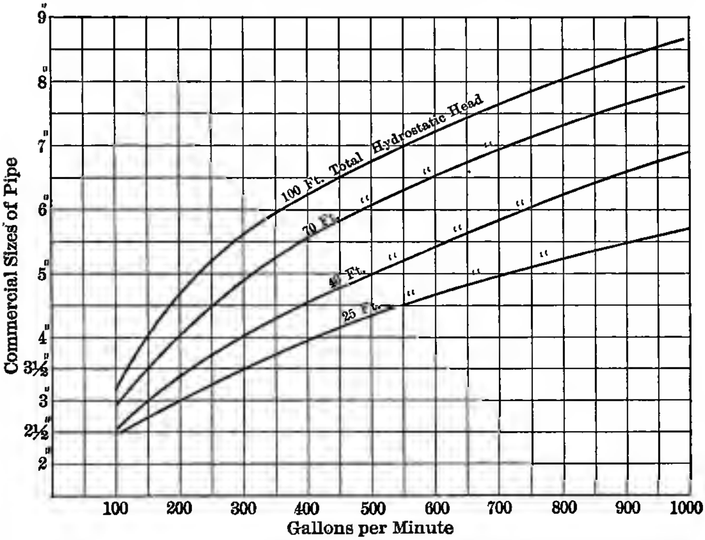


DIAGRAM 12

SIZES OF PIPE SUITABLE FOR DIFFERENT HEADS AND DISCHARGES BETWEEN 100 AND 1,000 GALLONS PER MINUTE

up to a total hydrostatic head of 100 feet the commercial size of pipe which should be used in order that the friction head may be kept below a certain maximum. In using the diagram for the case being considered, find 300 gallons per minute on horizontal scale and trace vertically upwards to the curve marked 40 feet hydrostatic head.

The lift in the present case is 45 feet, but since we can use only the nearest commercial size, which as seen by the

scale at the left is 4-inch pipe, it is unnecessary to interpolate. Hence, provisionally a 4-inch pipe for the discharge will be adopted. Referring now to Diagram 13 we find a means of determining the head to be allowed for friction.

Following vertically upwards from 300 gallons per minute, on the horizontal scale at the bottom, to the curve

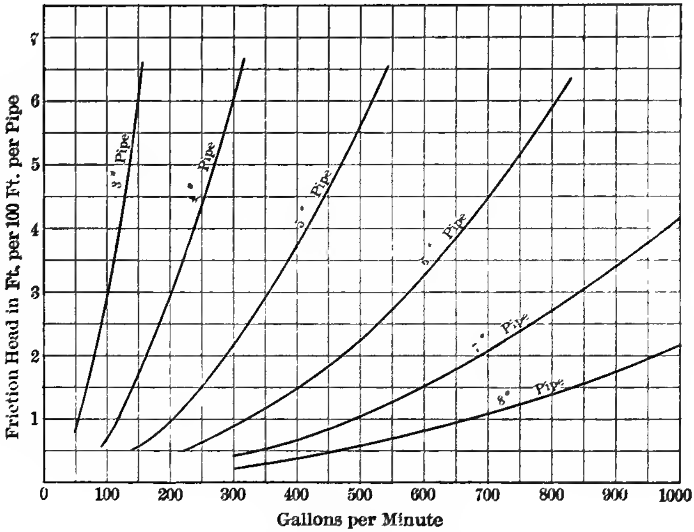


DIAGRAM 13

FRICTION HEADS FOR DIFFERENT SIZES OF PIPE 100 FEET LONG DISCHARGING VARIOUS QUANTITIES OF WATER

marked 4-inch pipe, we find the corresponding friction head for 100-foot length of pipe is about 6 feet. For an allowed length of 50 feet in this case, the friction head will be 3 feet, and consequently the total head will be 48 feet.

An examination of the characteristics of various pumps as given in the diagrams (pages 77–83) will enable us to construct the following table:

TABLE VIII

SPEEDS AND EFFICIENCIES OF VARIOUS PUMPS FOR 300 G. P. M. AND 48 FT. TOTAL HEAD, AS DERIVED FROM DIAGRAMS OF PUMP CHARACTERISTICS, PAGES 77 TO 83

Pump No.	Speed R. P. M.	Eff'y %	Size Discharge Pipe
1	960	48	2½
3	1,120	45	4
7	860	27	6
8	650	35	6
10	900	53	4
11	560	45	4

This table gives two criteria which may be used as a basis of selection: first, the speed; second, the efficiency. In general, it may be said that a slow-speed pump is preferable, unless it is to be driven by an electric motor (in which a higher speed is desirable, particularly in direct-connected sets), because of the longer life and greater durability of bearings of the slow-speed machine. From this standpoint it would appear that pump No. 11 is preferable, since it combines a very moderate speed with reasonably good efficiency. From the standpoint of efficiency, however, it is evident that pump No. 10 is superior to the others, particularly since the speed, 900 R.P.M., is by no means excessive. In case fuel cost is high, No. 10 should be chosen; if fuel cost or power cost is relatively unimportant, choose No. 11, assuming that the pumps themselves sell at about the same price. Under some circumstances it may be desirable to operate the pump for short periods at a greater or less capacity than that above given. It must be understood that this is a poor policy in general, for it will usually mean a very considerable lessening of efficiency unless the efficiency curve is quite flat over a considerable range of speed. The relation between speed,

horse-power input, and efficiency for any given head may readily be deduced from the characteristic curves of the pump and for the purpose of illustration this has been done for pump No. 10 when working at 48 feet head. The characteristic curves for this case are shown in Diagram 14. Although the total head will vary as the discharge changes, due to change in frictional head, it is difficult to show this

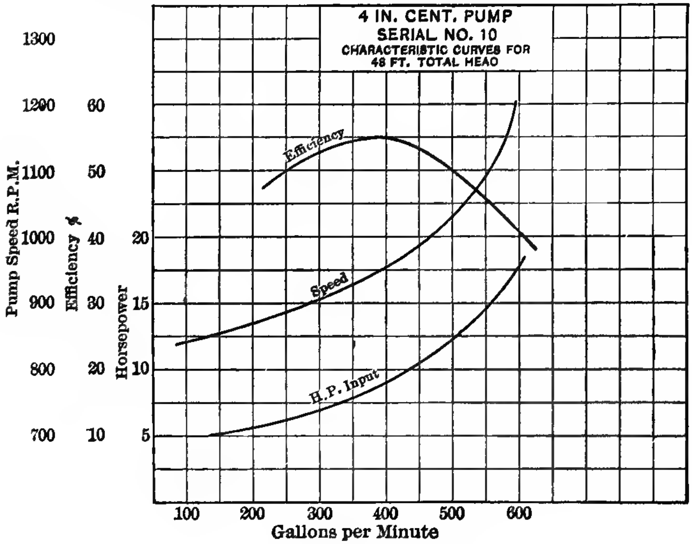


DIAGRAM 14

on a diagram and consequently Diagram 14 merely shows how a change in speed affects efficiency, horse-power input, and discharge when the head is constant. The conditions represented by this diagram show very closely what actually takes place when a pumping-plant operator for any reason changes the speed of his engine or motor or alters the ratio of driving to driven pulleys. As may be seen from the diagram, this pump will deliver 300 G.P.M. through 48 feet total head when operated at a speed of 905 R.P.M.

It will require 6.7 horse-power delivered at the pump pulley to accomplish this and the pump will have an efficiency of about 52.5 per cent. This is not the highest efficiency which may be attained by this pump, but it is that at which it will operate when fulfilling nearest the required conditions. Now as may be seen from Diagram 14, the discharge may be increased to double the amount, or to 600 gallons per minute, by increasing the speed to about 1,220 R.P.M., but it will be noted that the efficiency drops rapidly so that at this speed and discharge the efficiency is only slightly over 40 per cent., the horse-power input not being proportional to the discharge, but increasing more rapidly than the discharge increases. Consequently, about 20 per cent. more fuel will be used, or power will be consumed, per unit of water pumped at the higher speed than at the lower speed, and it would evidently be unwise, from the standpoint of economy, to operate the pump for any length of time under these conditions. This will be especially true in case an electric motor is used, since if it is rated at a horse-power corresponding to the 300 gallons per minute discharge, it will be seriously overloaded and will heat badly at the higher discharge, if indeed it can be made to develop the greater power required, belt drive being assumed and the speed change being secured by change in pulley ratio.

Size of Engine or Motor

The foregoing naturally brings up the question of the size of engine or motor to use. For convenience, the case above given will be considered further. As may be seen in Diagram 14, the actual horse-power required at the pulley of the pump for a discharge of 300 gallons per minute against 48 feet total head is 6.7 horse-power. Allowing for belt slippage and other losses, an engine or motor would be required

rated to deliver from 7 to 8 horse-power. Although in general a gasoline engine should give its most economical fuel consumption at or near its rated power, the tendency of most engine manufacturers seems to be to over-rate gasoline engines, and it would probably be better, therefore, to provide an engine rated at 9 to 10 horse-power. This will leave a slight overload capacity available, and the engine would probably be found to govern better and work more reliably than would the engine which is loaded up to its rating. With an engine capable of delivering 10 horse-power it would be possible, as may be seen from the curves in Diagram 14, to secure 400 G.P.M., approximately, in case the necessity arose and provision was made for changing speed. A properly designed engine or motor will, of course, have a definite and fairly constant speed, and although it is possible to change this speed over a slight range, the engine-driving pulley and the pump pulley should be so selected that the proper pump speed will result as based upon the mean speed of the engine or motor. Generally the size of the pump pulley is fixed, and cannot be altered because of the design, and consequently the size of the engine pulley must be specified. Ordinarily it will be found expedient to use a clutch pulley on a gasoline engine, this being supplied at a reasonable price as an extra by the engine builders. Let it be assumed that an engine of the size contemplated runs at a speed of 300 R.P.M. The pump in question is to have a speed of about 900 R.P.M. and it has an 8-inch pulley. It is evident, therefore, that the engine clutch pulley should be $\frac{900 \times 8''}{300} = 24''$ diameter, and this size should be specified when the engine is purchased. Too much emphasis cannot be placed on the proper selection of engine as to type and size and to securing the proper speed for the pump, since the economical

operation of the plant depends upon securing the highest efficiency possible from the pump and working the engine under such conditions as will promote the use of a minimum quantity of gasoline per unit of power developed.

Pump Builders' Diagrams

The above desirable conditions of operation will only be secured when those operating pumping plants or con-

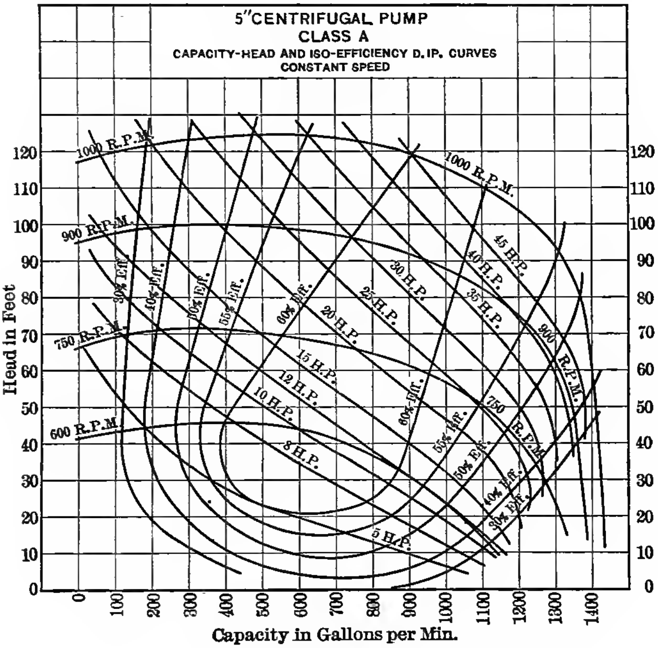


DIAGRAM 15

templating their erection give their attention to the characteristics of pumps similar to those described and illustrated in the preceding pages and pump builders are willing to supply authentic curves in connection with

their catalogues similar to those in Diagrams 15–16–17. These were furnished the writer through the courtesy of one of the largest builders of pumping machinery in the country, and are particularly valuable in the light they throw upon the characteristics of the various sizes of pumps considered.

The use of these diagrams is essentially the same as

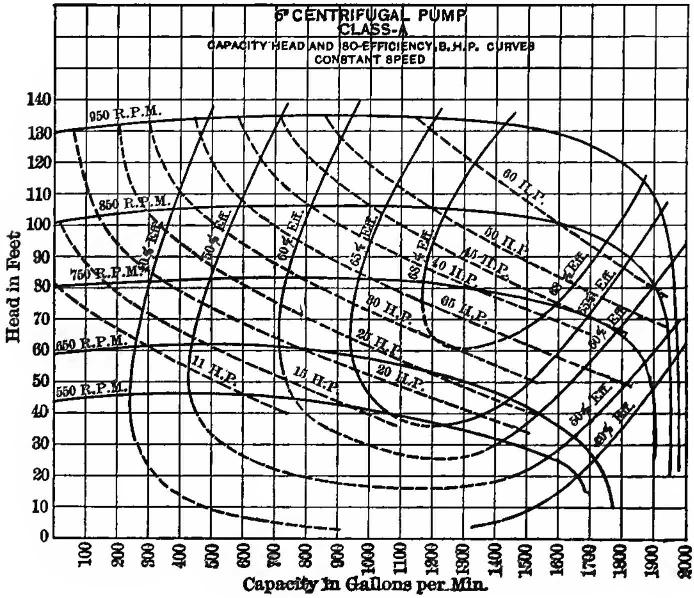


DIAGRAM 16

those already described, although by them it is somewhat easier to interpolate between curves. To illustrate the use of the diagrams, let it be supposed that it is desired to obtain 800 gallons per minute, pumped through a total head of 70 feet. The questions to be solved are (1), the best size of pump to use; (2), the efficiency at which it will operate; (3), the horse-power necessary to be pro-

vided; (4), the speed at which it must operate. Let it be assumed that the pump is to be operated 90 days of 24 hours each during the year and that power is supplied by an electric motor, current for which costs 2.8 cents per K.W. hour.*

The costs of the three pumps whose characteristics are

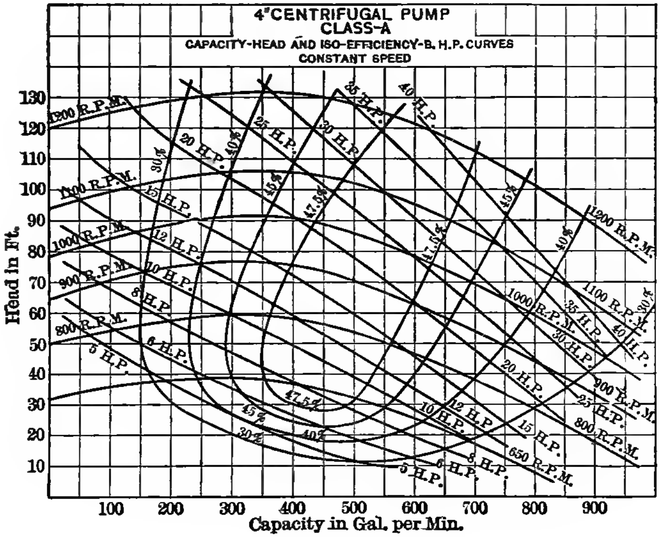


DIAGRAM 17

shown in the diagrams and as arranged for connection to an electric motor are:

4-inch pump......... $215.00 net F.O.B. cars factory.
5-inch pump......... $255.00 net F.O.B. cars factory.
6-inch pump......... $300.00 net F.O.B. cars factory.

* The cost of electric power is frequently fixed by a sliding scale so that there is a certain minimum charge whether power is or is not used, and the greater the amount of power used the less is the charge per K.W. hour. (See page 144.)

Referring to the diagrams, the following information is given as shown in the following table:

Table showing characteristics of three pumps delivering 800 gallons per minute through 70-foot total head.

Pump	Speed R. P. M.	Eff'y %	H.P. Required
4″	1,075	41	35
5″	785	60+	23
6″	690	62	24

Although a fairly slow speed is desirable, none of the speeds above given are to be considered excessive, but, other conditions being the same, the 6-inch pump would be selected from this standpoint alone. In the estimate of depreciation, however, it must be assumed that the depreciation of each pump increases in almost direct proportion to its speed. Thus letting depreciation on the 6-inch pump be 8 per cent., on the 5-inch pump it will be 9.1 per cent., on the 4-inch pump 12.5 per cent. Assuming that money commands 8 per cent. interest and that the yearly length of service as before stated is 90 days of 24 hours each, we may construct the following table giving yearly cost.

Pump	Pump Interest and Depreciation	Motor Interest and Depreciation	Yearly Cost of Power	Total Yearly Cost*
4″	$44.10	$160.00	$2,820	$3,024
5″	43.60	120.00	1,850	2,013
6″	48.00	120.00	1,935	2,103

* Not including attendance and cost of lubrication, or interest and depreciation on other parts of plant which would in every case be about equal.

The final column in above table should be used as a basis of judgment in a decision as to size of pump, since it includes interest and depreciation on the plant and the cost of power. It is also evident that, since the 4-inch pump requires a larger motor because of the greater horse-power required, it will be more expensive in first cost. It is evident that the 5-inch pump is the one which should be selected for the assumed conditions. It will be noted that yearly cost of power in above example is really the decisive factor, but, as may readily be seen, this factor will decrease in importance as the number of days of the year during which the plant is operated is decreased. The foregoing method of selection of a pump is suggested as being advisable when curves similar to those of the diagrams are available and when some approximate estimate of length of time of pumping and cost of power may be obtained.

Pump Equations

An examination of the characteristic curves and an investigation of the efficiencies of the various pumps as given in the preceding pages, must lead one of an inquiring mind to wonder, first, why an average of 50 per cent. of the work or power applied to pumps of the types tested should be lost in transforming that work into energy of flowing water, and second, since the curves showing relation between head and discharge for constant speed seem to follow the same law for all pumps, why it would not be possible to express this law by a mathematical expression containing factors which properly would take into account the peculiarities and proportions of the pump. To the solution of the first question the present investigation, unfortunately, can offer no clew beyond confirming the fact that power losses are unquestionably (and apparently unnecessarily) large in pumps of the size of those tested. It

would seem to offer a very fruitful field of investigation and experimentation, particularly on the part of manufacturers, to devise some simple shape or arrangement of impeller and casing to do away with the losses from shock and friction which now accompany the change from velocity head to pressure head in small centrifugal pumps. And experiments seem to show that, in sizes of over 6 inches and in a few cases of that size, the designs of some manufacturers have been so worked out that efficiencies of 75 per cent. and over have been attained. There seems to be, in sizes below 6 inches, the opportunity for some manufacturer to produce a simple centrifugal pump so designed that it will equal the efficiencies attained by larger sizes and yet will not be unreasonably high in price.

To return to the subject of loss of power in the centrifugal pump, it may be said that it undoubtedly occurs through a combination of friction, shock, and eddy effects in all pumps, and to the eddy effects, etc., must be added the leakage through clearance spaces in the more poorly designed and built pumps. The nature of these losses, how they vary, their relative or absolute amount, and the best means of preventing them, all remain yet to be discovered, and the subject offers a most engaging field to investigators provided with the requisite equipment and resources.

The second point referred to, namely, the question of finding some expression governing the relation between discharge and head at constant speed, can be answered to some extent by a consideration of the theoretic relations in the light of the curves given and the proportions of the various pumps.

The chief factor in connection with the theory of centrifugal pumps is the head or vertical distance through which the water may be pumped. This is shown by theory to be directly proportional to the square of the

speed of the impeller or rotating part of the pump. The head actually realized is less than the theoretical by the effect of water friction losses in the passageways surrounding the impeller and leading to the pump outlet, and in shock or impact effects at entrance to and upon leaving the impeller. We may therefore write:

Actual head $= h = H - h_1 - h_2 - h_3 - h_4$
= theoretic head — head lost in friction, etc.

Where h = actual head realized in feet.
H = theoretic head in feet.
h_1 = head lost in impeller.
h_2 = head lost in discharge chamber.
h_3 = head lost by impact at entrance to impeller.
h_4 = head lost by impact at exit from impeller.

Now, as is well known, water friction losses are proportional to the square of the velocity. Hence:

Let S = velocity of water passing through impeller.
T = velocity of water in discharge chamber.

V_1 = velocity of outer periphery of impeller.
V_2 = velocity of inner periphery of impeller.
R = radial velocity of water at entrance to impeller.

Then we may write:

$$H = J V_1^2$$
$$h_1 = M S^2$$
$$h_2 = N T^2$$

Where J, M, and N are constants of proportion.

Impact at exit from impeller may be considered to be proportional to some quantity $P V_1 (S + V_1)$, since it is zero when V_1 is zero, it increases as S increases, and becomes merely a frictional effect proportional to V_1^2 when $S = 0$. In this equation, P again is a constant of proportion. The

effect of impact at entrance to impeller may be written in a similar way, since at impending delivery there is no impact and the loss at entrance to impeller is then a frictional effect which during discharge must be proportional to the combined effect of radial and peripheral velocities. Hence for the loss of head at entrance to the impeller we may write:

$$h_3 = C\,V_2\,(R + V_2).$$

But since R is proportional to S and since V_2 is proportional to V_1 we may write $h_3 = B\,V_1\,(S + V_1)$ or the loss at entrance from friction and impact is proportional to the loss at exit.

Combining various terms we may write:

$$h = JV_1^2 - MS^2 - NT^2 - BV_1\,(S+V_1) - PV_1\,(S+V_1)$$

Now T may be taken as proportional to V_1, since the water in the discharge chamber evidently rotates at some less velocity than V_1 and we may therefore write $T^2 = L\,V_1^2$ where L is a constant.

Expanding and substituting, we may write:

$$h = JV_1^2 - MS^2 - NLV_1^2 - BV_1S - BV_1^2 - PV_1S - PV_1^2$$

or

$$h = (J - N\,L - B - P)\,V_1^2 - M\,S^2 - (B+P)\,V_1\,S.$$

Let $(J - N\,L - B - P) = K_1$

Let $M = K_2$

Let $B + P = K_3$

and we have

$$h = K_1\,V_1^2 - K_2\,S^2 - K_3\,V_1\,S$$

as representing the equation for the actual head realized by a centrifugal pump, taking into account losses by friction and impact. In this equation S may be represented by the term $\frac{Q}{a}$ where Q = the discharge in cubic feet per second

and a = the total area of water passages through the impeller normal to the flow line at exit. Hence:

$$h = K_1 V_1^2 - K_2 \frac{Q^2}{a^2} - K_3 V_1 \frac{Q}{a}$$

In this equation the constants K_1, K_2, and K_3 will evidently be applicable to only one type and size of pump, but it is of interest to determine what is the absolute value of such constants and how they compare for different pumps. To determine the constants, use was made of the method of least squares, which, although very laborious, is the only reliable method of so combining a series of observations that the resulting equation will be the best possible average of all the observations. The method was applied to the head-discharge curves of pumps Nos. 1, 3, and 10, and from these observations the following equations were derived:

$$\text{Pump No. 1, } h = .00366\frac{D^2 N^2}{2g} - 9.15\frac{Q^2}{2ga^2} - .0091\frac{DNQ}{2ga}\cos\alpha$$

$$\text{Pump No. 3, } h = .003355\frac{D^2 N^2}{2g} - 9.31\frac{Q^2}{2ga^2} - .00947\frac{DNQ}{2ga}\cos\alpha$$

$$\text{Pump No. 10, } h = .00336\frac{D^2 N^2}{2g} - 2.749\frac{Q^2}{2ga^2} - .0208\frac{DNQ}{2ga}\cos\alpha$$

It will be noted that the equations have been slightly changed from the general form above given and that a factor, "cos α" has been inserted in the last member to take account of the angle of the vanes. In these equations:

D = Diameter of impeller over vane tips in feet.
N = Speed of impeller in R.P.M.
2g = Twice the acceleration due to gravity = 64.4.

The agreement of these equations, or the curves which

they represent, with the actual curves found from the tests of the pumps is shown in Diagram 18.

As will be seen, the general form of the curve given by the equation seems sufficiently close to the actual curves to warrant the belief that the assumptions upon which the original equation is based are essentially correct. It would, therefore, be possible by such an equation to predict the

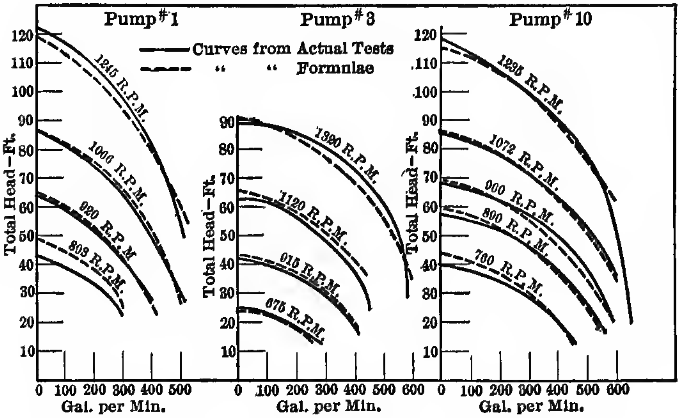


DIAGRAM 18

performance of the particular pump at any speed, head, or discharge if two out of these three conditions are known. As will be seen, however, the correspondence between the constants of the three equations is not sufficiently close to allow the equation determined for one pump to be used as a basis for predicting the performance of another. It would seem, therefore, that there is still lacking some factor dependent upon the size or proportions of the pump which must be used in the original equation to make it really general, that is, applicable to any series of pumps. It is thought, however, that the fact that an equation may be made to apply, within a reasonable degree of accuracy, to

the performance of even one pump throughout the range of working conditions, is sufficiently interesting to be worthy of notice.

Locations and Conditions Suitable for Centrifugal Pumps

The head against which water must be pumped and the capacity desired are the two factors which largely decide the question of whether a centrifugal pump is or is not suitable in irrigation work. So far as their construction is concerned it is now possible to negotiate almost any lift under 1,000 feet and the maximum quantity which can be lifted under such limitation of head is only limited by the amount of power available and the difficulties in making large-sized castings. Centrifugal pumps are in successful operation where 3,000 horse-power is absorbed by a single unit, but such an example has no bearing upon those problems connected with irrigation from wells where 1,000 gallons per minute is the maximum quantity which may be developed successfully from a single well and where heads of over 100 feet belong only to those situations where fruit growing make such lifts profitable. Where the supply is pumped from an open water source, as a river or reservoir, and is to be delivered into canals or distributaries, 5,000–6,000 gallons per minute have been handled with success in a single unit, but at comparatively low heads.

In general it may be said to be feasible to use centrifugal pumps under the following conditions:

In single units—

(1) In pumping from open water source for supply of under 10,000 gallons per minute.

(2) In pumping from wells where the pump may be placed not over 5 feet above standing water level, where total depth to water does not exceed 100 feet, total head

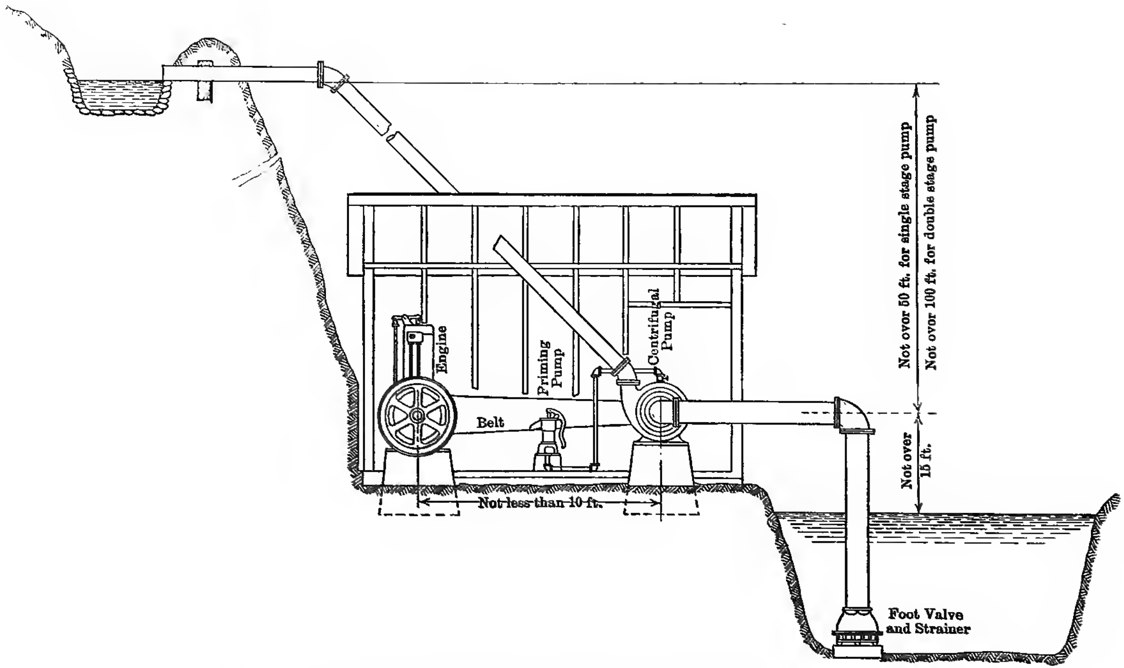


FIG. 24.—A small, cheaply built plant of type frequently installed for pumping from ditch on to higher bench land. See page 108.

does not exceed 125 feet, and quantity pumped does not exceed 1,000 gallons per minute.

The limitation in depth in (2) arises from the difficulty and expense of sinking a pit of the size necessary for a pump installation to a depth greater than 100 feet. The limitation as to head in the same instance arises from the practical difficulties in operation inherent in centrifugal pumps when heads as much or greater than 125 feet are encountered. The writer bases this statement upon his belief, based upon experience, that the multi-stage pump used in such cases is not free yet from serious objections due to end thrust and internal leakage, the first due to high pressure and weight of shaft in case of vertical pumps and the second due to the fact that well-water is likely to be heavily charged with fine sand which under high pressure forces its way into intermediate bearings and stuffing boxes and quickly causes serious wear and leakage. Doubtless means will be evolved in time which will eliminate these difficulties, but the writer has yet to learn of a centrifugal pump for these conditions in which the design has been so far perfected that when operated by the average man under practical conditions, the difficulties above mentioned will not arise. To obviate the necessity of a pump pit and yet use the centrifugal principle in very deep wells, a form of centrifugal multi-stage pump of such size that it may be lowered inside of a large size well-casing has been put on the market in recent years and under favorable conditions of operation has given much satisfaction. It is, however, an expensive type of pump and of limited capacity. Its use is more especially recommended for water-works' use, or for locations where water has acquired a high value for purposes of irrigation, so that the initial expense is justified. See Fig. 13, page 65.

CHAPTER VIII

DIFFERENT TYPES OF INSTALLATION FOR CENTRIFUGAL PUMPS

THE head to be pumped against, the depth to water, and the character of power to be used are determining factors in the decision as to the character of pump and general arrangement of plant, and every plant design must to a certain extent be based upon a study of local conditions. It is possible, however, to give a few examples illustrating certain types of installation which have been found satisfactory in practice and the designer may then vary the details to suit local or special requirements.

PLANT No. 1

The plant shown in Fig. 24 is that which it is customary to adopt where a limited quantity of water is to be lifted to adjacent high lands from an open water source. (In the case shown in Fig. 24 this is supposed to be a canal.) In such a case the pump is set up on a firm foundation at such elevation that the suction is not, say, over 10 feet vertically above the lowest water-surface elevation of the source.

The design shown in Fig. 24 may be modified and materially improved by providing a concrete-lined sump or pit beneath the pump house with a passageway leading to the canal. In this passageway grooves should be left in the concrete for the insertion of screens or trash racks and possibly stop planks or a gate, to keep water out of the sump in an emergency or for cleaning. This scheme

also allows the pump and motor to be placed further away from the canal on a more secure foundation and permits the use of a short vertical suction pipe which is a very desirable consideration. In some cases where a long discharge pipe is necessary to reach the point of gravity distribution, it may, according to the nature of the ground, be cheaper to dig a supply ditch or canal some distance inland from the source and place the plant closer to the point of discharge, eliminating more or less expensive discharge pipe, and possibly enabling a smaller size to be used.

Friction Effects.—It must be remembered that the friction effect tends to increase the suction lift just as it does the lift on the discharge side and the distance from the inlet of the suction pipe to the inlet of the pump must not be great enough to cause a friction head which together with the vertical suction lift will much exceed 25 feet, which must be considered the economical limit of suction lift. Many turns and valves also increase the friction effect.

Example.—An example will probably make this more clear. Suppose a 4-inch pump is to be used. This size refers, as previously explained, to the diameter of the discharge opening of the pump. The suction opening is usually at least one size larger or say 5 inches. The suction pipe should in no case be less than the size of the suction opening of the pump and if the suction pipe is to be of considerable length it should be at least two sizes larger than the nominal size of the pump. Let us say that in this case 5-inch pipe should be used on the suction line. Assume that the pump is placed 10 feet above water level and that the distance from the strainer to the pump is 100 feet measured along the axis of the pipe. Also assume that there is a foot-valve on the strainer and two elbows in the line. If the pump discharges 500 gallons per minute,

the friction head for a 5-inch pipe of the length assumed will be about 5.5 feet. (See Diagram 13.) The loss of head in the foot-valve will be about 2.8 feet and in the two elbows about 2 feet. The velocity head will be 1 foot. The total suction head will therefore be found as follows:

Hydrostatic head	10.00 ft.
Loss of head foot-valve and strainer	2.80
Friction head in 100 ft. 5-inch pipe	5.50
Friction head, two elbows	2.00
Velocity head	1.00
Total suction head	21.30 ft.

It is apparent from this example that the effect of friction in a long suction pipe may be to increase the suction head by more than double the actual vertical lift and for this reason, if for no other, it is advisable to have a suction pipe as short and direct as possible. Of course the use of a large pipe will much reduce the friction head, but it is advisable, if possible, to limit the length of the suction pipe to a minimum from the standpoint of operation, since where we have a long and crooked pipe we also have many joints which it is always difficult to keep perfectly tight, as they must be with any centrifugal pump, a slight air leakage into the suction cutting down the flow tremendously, and when serious enough, stopping the flow entirely.

Drive.—The drive, in the case illustrated by the figure, is by gasoline engine, though steam or electric power could be used as well. It is advisable to use a generous length of belt for centrifugal-pump drive, the distance between the engine and pump centers being from 15 to 20 feet.

Priming.—For priming the centrifugal a common pitcher pump may be used. This should be connected by ¾-inch pipe to the pipe connection to be found on the top of the centrifugal pump casing. An ordinary globe valve, or,

what is better, a good check opening outwards should be placed in this line and after the priming has been accomplished the operator should be sure that no air leaks into the centrifugal through this line. If the pump is to be primed each time it is started, a check valve must be placed in the discharge pipe immediately above the pump, and in any case where the pipe discharges into a tank there must certainly be provided a check valve to prevent the emptying of the pipe or tank when the pump is stopped. If no check valve is used the priming pump is useless and a foot-valve at the strainer is necessary. In this case, to prime the pump when it is started the first time, the plug on top of pump casing must be removed and water poured in through the opening till the suction pipe and pump are full. This presupposes, of course, a tight foot-valve, and if it remains so there will be no subsequent necessity for priming. Foot-valves are, however, subject to derangements, and after a stop of a week or so it is no uncommon experience to find that all the water has leaked back through the foot-valve and the tedious process of priming must be repeated.

Ejector Primer.—Where a check valve is used, the discharge pipe is large or long and the head over 50 feet, thus providing a considerable supply of water stored at the necessary pressure, a very convenient method of priming is by the use of a water ejector attached to the centrifugal similar to a priming pump and using for its operation water taken through a small pipe connection from the discharge pipe. As long as water remains in this pipe other means of priming will not have to be resorted to, but must be provided and held in reserve. For power-driven priming pumps the use of a small water pump with a discharge pipe carried sufficiently high to insure that the valves will always be immersed, is preferable to an air-pump which must be stopped as soon as the centrifugal is primed

to prevent damage to piston and valves by water caught in the clearance.

Discharge Pipe.—The same statement as to size and alignment of pipe from the standpoint of friction applies to the discharge as to the suction. A small pipe with many elbows and bends causes unnecessary friction losses, and it is a direct saving of power to use large pipe and as few elbows as possible.

Water Hammer.—An important matter in connection with design of discharge pipe is water hammer. When a pump is suddenly stopped, as in the case of a motor-driven unit by the circuit breaker tripping, there is a surging back and forth set up in the discharge piping which for a few seconds may multiply by many times the usual working pressure. If a check valve is used this excess pressure comes upon it and the discharge pipe, but when a foot-valve is employed the hammer effect is also expended upon the pump case and suction pipe. With very long discharge pipes and heads of over 50 feet some reliable means should be employed to relieve excess pressures. This may take the form of quick-acting relief valves with a free water passage at least one-tenth the area of discharge pipe, or it may be a large air chamber or a vertical surge pipe connected to the discharge above the check valve.

Fittings.—Where, as is illustrated, the water is to be conveyed to a point immediately above and adjacent to the plant, it will be found an economy both in the saving of pipe and of power, through lessened friction losses, to use 45-degree elbows in the discharge line. "Long Sweep" fittings should be used wherever right-angle turns are made either in suction or discharge pipe, and if stop valves are used they should be gate valves rather than globe valves. The use of the latter cannot be too strongly condemned in

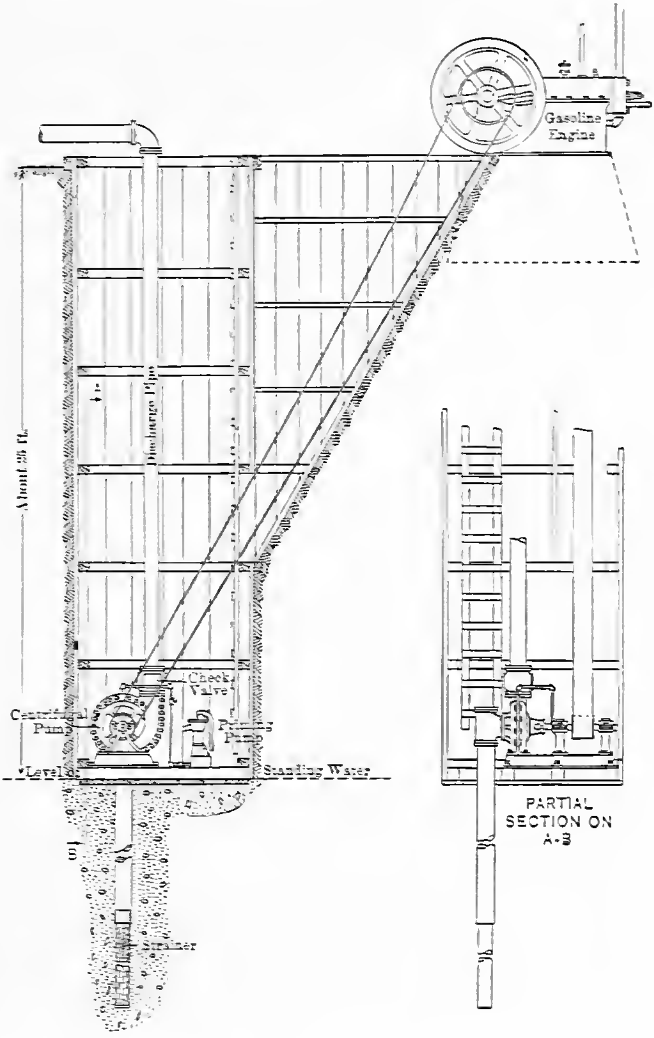


Fig. 25.—A common type of plant for pumping from driven well, where water is found at shallow depths.

water-piping in general, but particularly in any case where economy in power is a consideration, since it is to be remembered that a globe valve causes the same friction head as would be caused by 100 feet of the same nominal size of pipe.

Pump.—As to the type of pump to use for a plant such as is illustrated in Fig. 24, there is no question as to the eminent desirability of a horizontal centrifugal. If the total head is less than 70 to 100 feet the single-stage pump should be used, but for greater heads the necessary speed of the single-stage pump will be excessive for successful and long-continued operation and a multiple stage should be used. Where electrical power is available at reasonable cost a pump direct connected to a motor will be found most convenient. If a gasoline engine is used, it should be selected of a make known to be reliable. Some suggestions on this point will be found in Chapter XIII.

Plant No. 2

The pumping plant shown in Fig. 25 is of a type very common in those sections of the West where water is found at shallow depths, as in river valleys immediately adjacent to streams, and water is pumped either to supplement a gravity supply or is used by some fruit or truck grower for an independent and dependable water supply.

Pump Pit and Arrangement of Belt Drive.—In such a plant an open pit 6 to 8 feet square or round is first dug to water and lined with timber or in some cases with concrete. Owing to the use in this case of an inclined belt reaching from the engine at the surface to the horizontal centrifugal pump in the pit, such pits are limited to a depth of about 25 feet. With greater depths it is not feasible to

use the inclined belt, owing to its excessive length. It might be suggested that in order still to use the horizontal pump with deeper pits, a counter-shaft could be placed across the top of the pit from which a vertical belt might extend to the pump. This has, however, a serious disadvantage in the use of the vertical belt, which seldom works satisfactorily, besides which there is a loss of power in the use of the countershaft and two belts instead of one. With the inclined belt, the sag of the belt increases the arc of contact on the driving and driven pulleys and the weight of the belt gives the necessary adhesion to the pulleys without the excessive initial tension necessary for a vertical belt. Rope transmission has been suggested (and used in a few instances), for deep pits where it was desired to use a horizontal centrifugal pump, but the complication and expense of this form of power transmission do not recommend it for irrigation work.

Since for reasons just given this type of plant is limited to locations where water is found not deeper than 25 feet below the surface, it may be possible in firm ground to dig the pit without lining same as excavation proceeds, but as soon as the pit and belt chute have been completed, the lining should be put in without delay. For a really permanent structure and where the expense is not prohibitive, a 4- to 6-inch concrete lining should by all means be provided and, in case concrete is used, it will be found more economical in excavation and in use of concrete and but little more expensive in forms to make the pit circular. The inside diameter should not be less than 6 feet and the same minimum dimensions hold for a square or rectangular pit. In most cases a wooden lining will be used which under average conditions should last seven to ten years before it needs renewing. A common practice in building a wooden lining is to use 2″ x 6″ or 2″ x 8″ vertical sheathing inside

of which a 4″ x 6″ horizontal framing is spaced every 4 feet vertically.

Well Pipe and Strainer.—The pit having been lined, the next thing in order is the sinking of the well-tube, a job which should be left to the professional well-driller, but which may be negotiated by the layman if he has the necessary tools and the large amount of patience required, together with considerable ingenuity. The matter of well sinking has been considered in Chapter V. If the top of the strainer is from 22 to 25 feet below the level of ground water, the suction connection of the pump can be made directly to the top of the well-pipe, but in case of a shallow water-bearing formation or where for any reason the top of the strainer is less than 22 feet below the level of standing water, then a suction pipe or draft tube should be dropped down inside the well-pipe and strainer to at least 25 feet below standing-water level and the pump connected to this suction pipe.

Pump Foundation.—No floor is required usually in a well-pit, but the pump should rest on heavy timbers attached to the pit lining, since the material for some distance around the well-pipe is apt to settle considerably soon after pumping begins, particularly if much sand is removed, and unless the pump is securely supported independently of the floor, it is likely to settle out of alignment, not only making it difficult to run the belt properly, but possibly cracking a suction flange connection.

Fittings.—The connection at the top of the well-pipe or draft tube should be a tee capped with a blind flange, rather than an elbow, since in case there is considerable fine sand around the strainer it is likely to accumulate inside the strainer and considerably reduce the capacity of the well. With a tee connection on the suction pipe it is a very easy matter to remove the blind flange, lower a

sand bucket, and bail out the sand. In general, it will be found that it is decidedly more convenient to use flanged instead of screw fittings in all pipe work in the pit, due to the narrow quarters in which work must be done and the difficulty of using large pipe wrenches in making up screwed connections.

Immediately above the pump a check valve should be placed in the discharge line, since, there being no possibility of using a foot-valve in a driven well, a priming pump must be used each time the pump is started, to fill the centrifugal with water. In some cases, flap valves are used on the end of the discharge pipe and we have seen some small plants provided with nothing better than a large, tapered plug covered with a piece of rubber belting, which was driven into the end of the discharge pipe to make an air-tight end. The disadvantage in this, aside from its crudeness, is that air in the long discharge pipe must be partially exhausted by hand pumping before water will rise into the centrifugal pump to such an extent that it will prime itself and establish the flow. A check valve, suitable for the use named, may be purchased at a reasonable figure in any size desired from any machinery or well-supply house, and is a justifiable expense. This valve should, if possible, be of the "increaser" type, that is, one end should have a flange connection the same as the flange on the pump, but the other end should be provided with flange for the next larger pipe size, since in all but the shallowest wells and lowest lifts the discharge pipe should be a size larger than the outlet of the pump, in order to decrease the friction head.

It is also the part of wisdom to attach a vacuum gauge to the suction pipe near the pump. This may be done by boring and tapping out a hole for a ¼-inch pipe connection. The hole should be bored on the horizontal axis of the pipe

near the suction flange of the pump. The vacuum gauge will indicate the "draw-down," and will show whether the strainer is open and in good condition, and whether the underground supply is holding out. In case the strainer is not clogged, a gradual increase in the reading of the vacuum gauge will indicate that the supply is failing and that the ground-water level is being lowered by pumping or other causes. A sudden increase in the "draw-down" usually indicates a clogging of the strainer by sand or other material, and is a condition requiring immediate attention.

Drive.—Little need be said here regarding the belt drive, since it is a very simple matter where a chute, as indicated, is used. Figure 25, illustrating such a plant, shows a gasoline engine drive, but steam engine or motor drive might be substituted, if conditions warranted and it was not desirable to use a direct-connected plant, such as is indicated in Fig. 26.

Plant No. 3

This plant is similar in every way to that just discussed, except that the pump is direct connected to a motor mounted upon the same bed-plate. This is not recommended where the pit is likely to be very damp, or where there is a possibility at any time of the ground water rising to such an extent as to submerge the pump and motor. The depth of the pit in this case is limited merely by the fact that a pit rather large in dimensions is needed and consequently the limiting depth for the direct-connected pump may probably be placed at about 50 feet.

Advantages.—This type of plant has many advantages from the standpoint of convenience over an engine-driven plant, and is what might be termed a standard type for central station systems of pumping where electric power is

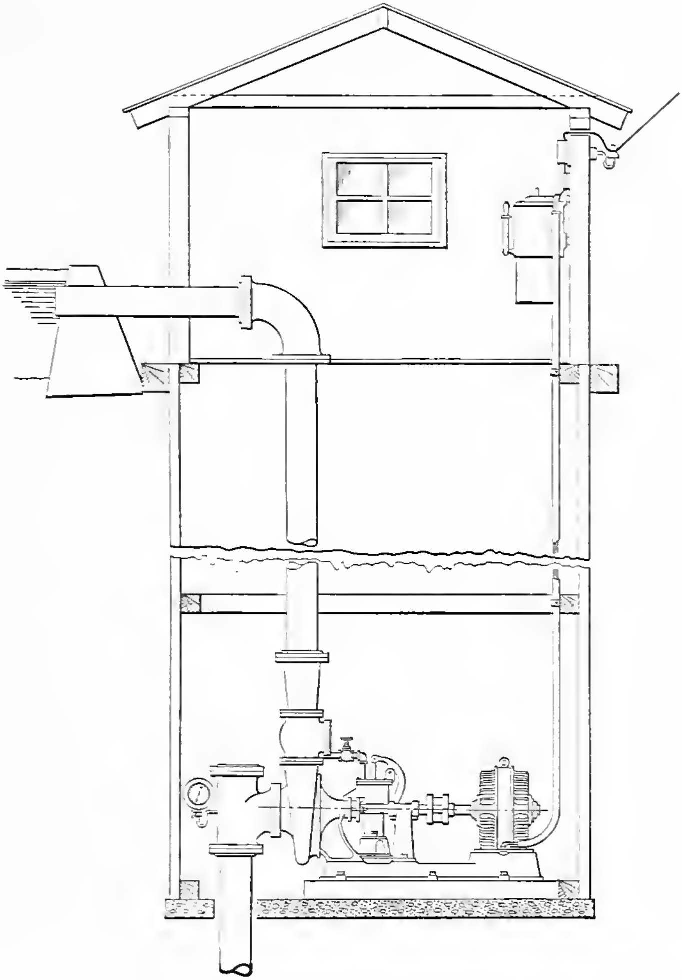


FIG. 26.—An electric-driven plant for pumping from depths within 50 feet. A standard type of installation for the individual plants in a central station project.

generated at some central point, and distributed over a considerable area to numerous individual plants of the type described. The power being alternating current of standard frequency and voltage in all cases, the motor is of the induction squirrel-cage type, and is practically fool-proof.

Pump and Motor Speeds.—It is of very great importance in direct-connected sets to have the pump so built or selected that at the motor speed, which is practically unchangeable, the greatest efficiency will be realized from the pump for the particular conditions of head and discharge that prevail at the given plant. Unfortunately, since stock pumps are used in these installations, and the motor speed will vary between 900 and 1,700 R.P.M. according to size and type, it only now and then happens that a pump is running at the speed at which it should run for the total head prevailing if a minimum current consumption is desired. By the use of characteristic curves as described in Chapter VII, this situation might be changed by choosing a pump which at the motor speed, the head, and discharge desired, would give a maximum efficiency. Lack of attention to this matter has discouraged several plant operators known to the writer, who, in paying excessive bills for electric current, were unknowingly paying for their lack of knowledge of the characteristics of a centrifugal pump. They were finally forced to abandon the use of electric drive in favor of gasoline engine or steam where inefficient plant operation does not so quickly make itself felt or noticed as is the case where one can see the dollars slipping away with every unnecessary revolution of the index of the watt-hour meter.

Wiring.—In the installation of an electric plant all wiring should be put in by an experienced electrician, and

the wires should be laid in conduits both in the pump house over the pit and in the pit itself down to the motor.

Attention Required.—If the priming pump is at the surface, as is possible where the pumping set is not over 25 feet below the surface, about all the attention required of the operator besides seeing that the pump is oiled (and this may be done from the surface, if desired), is to operate the hand pump until the centrifugal is primed and then by starting box to start the motor. No attention should be required by the plant during an eight- or ten-hour run, at the end of which time, of course, re-oiling is necessary.

Electric Drive the Ideal Arrangement.—Electricity very closely approaches the ideal power for irrigation pumping, and unless the local rates for current are excessive, it will pay one to consider its adoption very closely before deciding upon steam, producer-gas, gasoline, or distillate drive, since with these the expense for attendance is a considerable item in the total cost of pumping, but it is almost entirely obviated with electric drive. With some of the best gasoline engines, attendance may be a very small expense, but the writer has yet to learn of any gas-engine-driven plant in which the operator could leave it entirely to itself during an 8- or 10-hour day, thus being free to give his entire attention to the distribution of the water.

Plant No. 4

This, as shown by Fig. 27, is introduced to show a design similar to that used on one of the largest low-lift central station pumping plants in the West, in which water is pumped from a river and distributed over a large acreage by means of concrete-lined canals and ditches. As shown by the figure, A is the centrifugal pump of very large size, driven by an induction motor, B. There may be, and in the instance cited, are, several such sets in one pump-house.

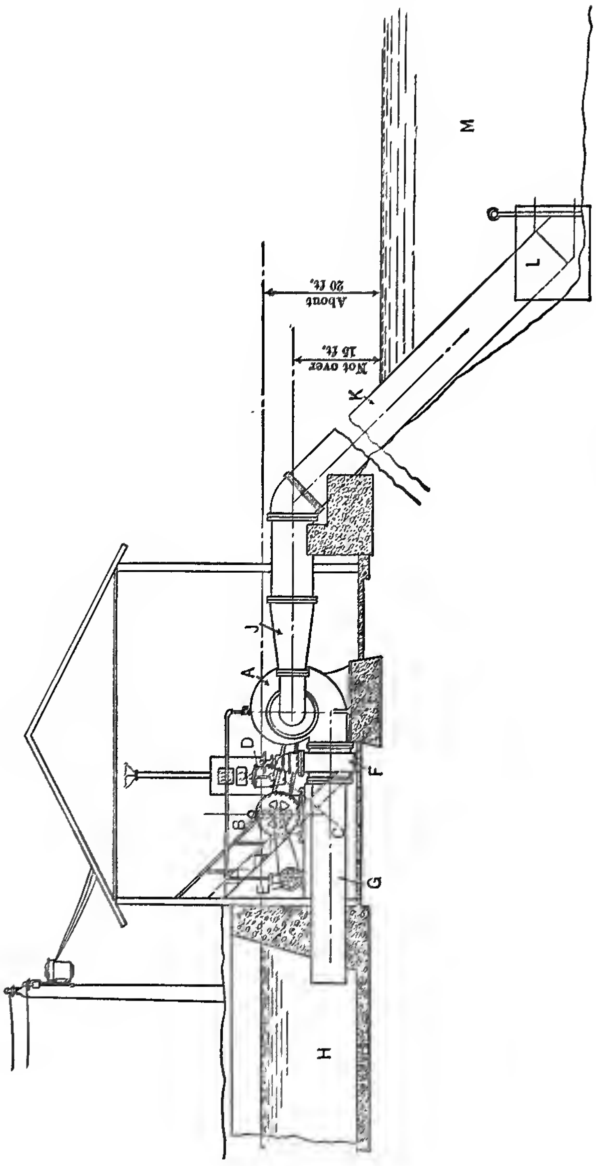


FIG. 27.—An example of a low-lift plant.

The drive is by a silent chain, C, which enables a relatively short distance between shaft centres to be used. E is the priming pump, and F is the valve in the discharge line used when priming the centrifugal. L is a strainer set in a block of concrete, and D is the starting box. It will be noted that practically the entire lift in this case is suction lift. In pumps of this size, relatively high efficiencies were attained in tests by the builders of the pump and are probably constantly maintained so long as operating conditions remain the same as those for which the pumps were designed. In some cases, indeed, pumps in use some time show better efficiencies than new ones, owing, doubtless, to the lessened water friction as the cored-out passages become smoother under the scouring action of the water.

Direct-connected units would probably be preferable to chain drive if the proper motor speed could be secured.

Applications of the Low-Lift Plant.—The type of plant illustrated by Fig. 27 is, of course, of limited application, since it is seldom that conditions are found similar to those for which this plant was designed. It may, however, in exceptional cases, be found cheaper to build a pumping plant rather than a gravity system, owing to slight river slope which makes a long canal necessary in order to reach the lands to be irrigated, or unfavorable conditions for a headgate, such as a shifting river bed, floods, etc., may sometimes justify the building of a pumping plant at some point adjacent to the lands to be irrigated. When either water-power or cheap coal is available, a careful study of relative costs may show a decided advantage in favor of a pumping plant similar in type to that shown in Fig. 27.

Plant No. 5

When the depth to standing water exceeds 25 feet, and for any reason an electrically-driven plant, as shown in

Fig. 26, is inadvisable or impossible, it is customary to adopt the vertical centrifugal pump, which is driven by a shaft extending from the surface.

Suspension Frame.—The pump itself is suspended in a framework of wood or steel, which is held at the surface by a trussed frame resting on the top of the curbing. By this method of suspension, the pump is kept in true alignment with the shaft and no difficulties are encountered, due to the sinking or displacement of the pump, as might occur if the pump were supported independently of the frame on a foundation built in the bottom of the pit. The framework is always provided with cross and diagonal bracing on a 6- or 7-foot spacing, and the cross-braces support self-aligning bearings for the vertical shaft, see Fig. 30.

Step Bearing and End Thrust.—At the surface is usually a cast-iron frame provided with ample bearings, to take the side thrust due to the pull of the belt, and a step bearing at the top, which takes the weight of the entire shaft, pulley, and impeller, and any unbalanced end thrust due to the action of the pump. This bearing is the most important bearing in the entire installation, and is the one which, if poorly made, is apt to give more trouble than all the rest of the installation combined. In some makes of pump, the end thrust due to the action of the pump is supposed to balance the weight of the shaft pulley and impeller, and elaborate means are provided to accomplish this end. Usually, however, it is found that such schemes are more or less of a failure, since a slight change in operating conditions, such as speed or head, cause an unbalancing of the system and the necessity for re-adjustment. In other pumps no attempt is made to balance the weight of the shafting pulley or impeller, the hydraulic end-thrust being eliminated by the construction of the pump, and the weight of the rotating parts is taken up by

ball or roller bearings in a well-designed step bearing. When well made, this latter type is likely to prove the more satisfactory under the conditions of irrigation work, although under stable operating conditions there is likely to be less mechanical friction loss and consequently a higher efficiency attained with the balanced step type.

Stages.—The number of "steps" or stages to adopt for the pump will depend upon the head. If the discharge is to occur at the surface and ground water is encountered at less than 50 feet below the surface, the single-step or single-stage pump may be used satisfactorily, but for greater distances below the surface a two-stage, or multi-stage pump should be used. Although there is no reason why greater depths should not be negotiated (as indeed have been in various parts of the West), the limiting depth for *really satisfactory* operation of this type of plant may be said to be reached when the pit reaches a depth of 75 or 80 feet. Vertical shafts longer than this increase, rapidly, the difficulties of operation, and for greater depths it will be advisable to use either electric drive with a vertical or horizontal direct-connected motor-driven pump or some other type, as will be noted later.

Priming.—For gasoline or electric drive, hand priming is necessary, unless a small electric-driven air-pump auxiliary can be afforded. If a hand pump be used for exhausting air from the centrifugal, it must be located at the bottom of the shaft, for it will be found practically impossible to make joints in a line reaching to the surface sufficiently tight to enable the pump for priming to be placed there. With steam-driven plants, a 3/4-inch or 1-inch steam line may be extended down into the pit to operate an ejector, which if used with a check valve between the ejector and pump, will obviate the necessity of going down into the pit

at all for priming, since the steam may be admitted into the priming line by a valve at the surface.

Discharge Pipe and Details.—The same remarks as to well-pipe connections, valves, and discharge pipe apply to this plant as to those previously considered. A large-sized discharge pipe should be used and long radius tees and elbows rather than common fittings.

Driving Pulley.—The pulley at the top of the vertical shaft should be so placed that a horizontal plane through the crown of the pulley will be about on a level, possibly

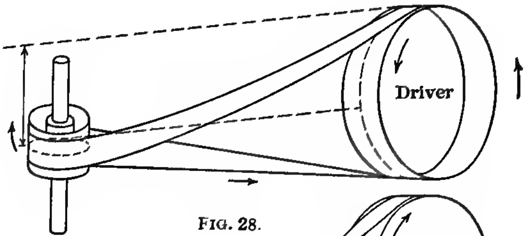


FIG. 28.

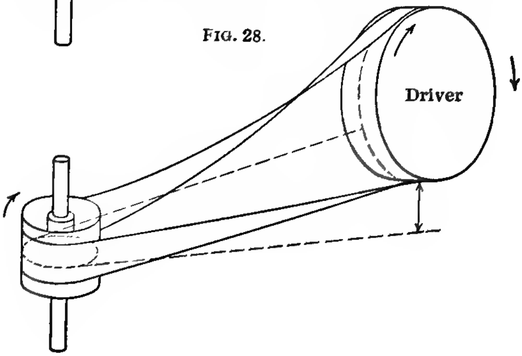


FIG. 29.

a little above, the centre of engine pulley, when this pulley rotates, as shown in Fig. 28. When the centres of the driving and driven pulleys are from 16 to 20 feet apart, as they should be in such case, the weight of the belt and

the pull of the tight side will cause it to lower on the vertical pulley as far as the tension will allow. It not infrequently happens that the vertical pulley has to be readjusted in position after the plant is put in operation and sometimes it will be found necessary to use an idler for this type of drive, but its use should be avoided if possible. It should when used be placed not less than 3 feet from the vertical pulley, and the highest part of its circumference should be placed on a level with the centre of the vertical pulley. In a vertical plane, that side of the circumference of the vertical pulley from which the belt leaves, should be tangent to a plane passing through the crown of the driving pulley of the motor or engine.

When the driving pulley rotates as in Fig. 29, a horizontal plane through the crown of the vertical, or driven, pulley should pass tangent to or below lowest portion of circumference of driving pulley. The same condition with respect to the vertical position of the vertical pulley holds as in the former case.

Plant No. 6

Vertical Electric Drive.—Where electric power is available, a very satisfactory type of centrifugal plant fulfilling the same purpose as stated for Plant No. 5 is shown in Fig. 30. The underground portion of this plant is in all respects similar to the one last described, but the drive is by an electric motor mounted vertically on a framework at the surface, and connected to the vertical shaft by a flexible coupling. A vertical thrust bearing takes the weight of shaft and couplings and the motor is self-contained, the weight of the revolving armature being taken up by a thrust bearing in the motor itself. Such a plant put out by an experienced and reliable manufacturer, although expensive, has many

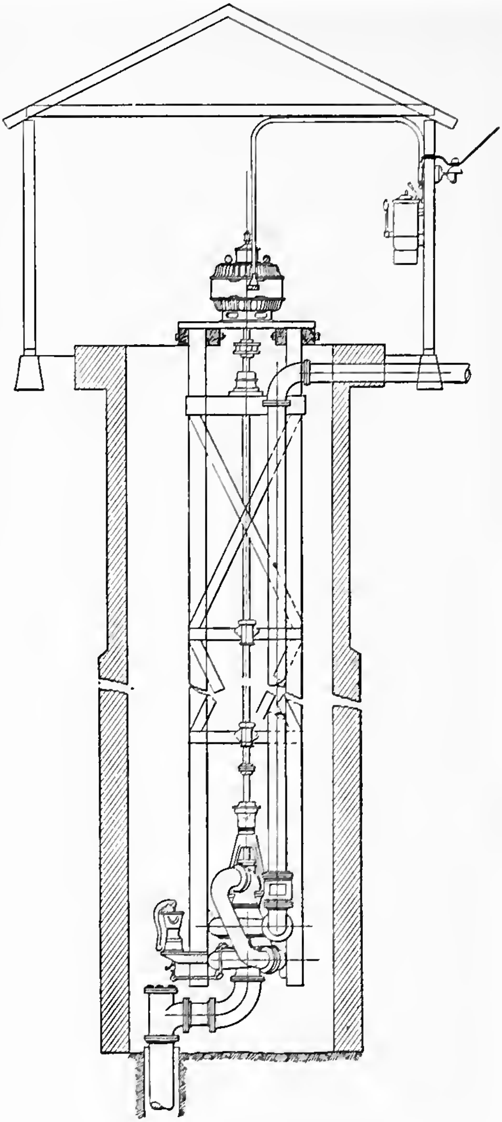


FIG. 30.—A type of installation for deep well pumping using multi-stage centrifugal pump in open pit.

advantages in point of durability and convenience over the type of drive illustrated in Fig. 28, there being no belting or idlers and the power being instantly available. This plant, like the one preceding, is, in the judgment of the writer, limited to pits not much exceeding 75 feet in depth.

MEANS OF WATER MEASUREMENT

In connection with an irrigation pumping plant, the importance of providing some means of measuring the discharge can scarcely be sufficiently emphasized, especially when centrifugal pumps are used. It enables a constant check to be made upon the performance of the plant, indicating when the pumps are falling off in efficiency or becoming clogged, or, in the case of the driven well plant, may indicate a fouling of the strainer or increase of drawdown. It enables efficiency tests to be made upon completion of plant, and facilitates such tests at intervals during its life to determine if efficiency is being maintained. The plans for a plant should, if possible, therefore, always provide some accurate means of measurement of pump discharge. This generally takes the form of a trapezoidal weir at or near the discharge outlet, though, if the slight increase in head thus caused is objectionable, a rating flume might be used. In some cases, a Venturi tube may offer the only feasible solution, as where the water is distributed over the area irrigated in underground conduits.

CHAPTER IX

TYPICAL PLANTS NOT USING CENTRIFUGAL PUMPS

When the depth to water is from 75 to 100 feet, the multi-stage centrifugal pump, while not at all impracticable, becomes increasingly difficult to operate, satisfactorily, in the hands of the average man who is not a mechanical expert or without long experience in this work.

The Question of Sand.—It must be understood, of course, that where much sand is apt to be pumped with the water, as is always the case when the strainer is landed in a body of water-bearing sand, the only economically feasible method of pumping is by the centrifugal pump. The air lift need not be considered in this connection, due to its well-known lack of economy. In case the sand problem does not enter in, then it may be well to adopt the type of plant shown in Fig. 31.

Duplex and Triplex Pumps.—In this case we employ a duplex or triplex pump with the working head at the surface and the pump cylinders in a pit a short distance above the level of standing water. The pump plungers are operated by rods extending between the pump cylinders and the working head, the rods being held in vertical alignment by roller guides attached to timbers extending across the pit at points spaced from 5 feet to 6 feet apart vertically.

Drive.—The working head may be driven by a steam or gasoline engine, but, where electric current is available, may be actuated by a motor connected either through gears or a silent chain belt.

Capacity Limited.—The capacity of such a pumping set is limited, since the number of strokes per minute cannot

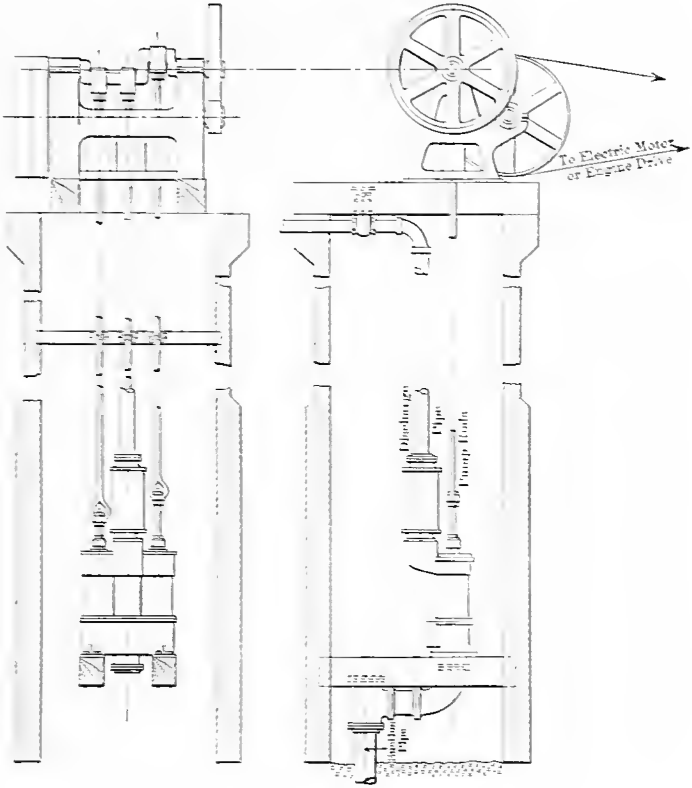


FIG. 31.—Showing use of triplex reciprocating pump in deep pit.

exceed a certain maximum, owing to inertia effects. With a given size of cylinders, the capacity of the pump will be the volume displaced per minute by the two or three cylinders multiplied by a certain correction factor for slip which, in a well-designed pump in good condition, should not be less than 85 per cent., that is, the amount of water lost by slip should not exceed 15 per cent. Such pumps are made in sizes having piston displacement of

from 50 to 300 gallons per minute at 40 working strokes per minute. These pumps for irrigation work should be provided with leather-packed pistons and rubber valves, since when so equipped they are less likely to be injured by sand. Brass-lined cylinders, although better in other ways, are likely to be more quickly scarred and ruined by sand than are those less expensive. The suction and discharge piping should be installed according to suggestion already given for other plants.

Advantages and Efficiency.—This type of pump has the evident advantage over a centrifugal in requiring no priming, it can be used in a pit of a little smaller dimensions, the difficulties attendant upon the use of long vertical shafting are absent, and finally, the mechanical efficiency is somewhat higher than in most centrifugal pumps and should in a well-designed and installed plant amount to between 70 and 80 per cent., figuring between the power input to the working head, and the energy of the moving water.

Vertical Rods.—The vertical rods must be in perfect alignment for satisfactory operation, and the pump cylinders must be very securely anchored, since the alternate pull of the rods in a deep pit is a very severe stress which must be resisted by the anchor bolts holding down the cylinders. In a plant of this type installed by the writer, the cylinders were bolted to a very heavy timber bedded horizontally in the concrete wall of the pit.

Deep Well Pumps

The limit of open-pit construction may be said to be reached at a depth of 100 feet, and if an irrigation supply is to be obtained from depths greater than this, it is probable that a study of the problem will limit the solution to

the use of some type of deep-well apparatus, *i.e.*, a pump cylinder in a driven well with a pumping head at the surface, or in exceptional cases a deep-well turbine pump might be recommended, although this is limited to wells of large bore and is expensive equipment.

Deep-well apparatus, either in the single and familiar single-acting pump cylinder or in the more complicated double-acting cylinders, and with various valves, etc., are made by a considerable number of makers, and competition in this line has developed a type of machinery which in the better grades affords a striking evidence of the attention now paid to details. In the pump heads we now find such details as white metal bearings, oiling systems, drop forgings, massive and well-braced frames, and so on, where formerly it was simply put together to be sold rather than to run.

Capacity Limited.—Deep-well pumps are not particularly desirable for irrigation work (aside from the fact that deep-well pumping is expensive) since the quantity of water developed by such pumps is usually far below the most modest requirements and the flow of many days' pumping must be stored in a reservoir in order to provide for one day's irrigation. The capacity of such pumps depends upon the diameter of pump cylinder, the length of the stroke, the number of strokes per minute, and the slip.

Speed.—In general, the number of double strokes or, in other words, the revolutions of the crank, should not exceed 40 per minute, and for extreme depths probably not more than 25, in order that the stresses due to the reciprocation of the long sucker rod and heavy plunger, and the inertia of the water column may not be excessive.

Drive.—Where electric power is available, the most satisfactory drive is a motor mounted on the same base as the pumping head, and geared to it by a rawhide or cloth pinion.

Belt drive from a steam or gas engine is equally satisfactory in case electric power is not available, and in this case it is advisable in selecting a pumping head to choose one in which the belt wheel is mounted as low as possible.

Important Details.—If a pumping head is desired in which there shall be freedom from annoying and costly breakdowns, attention should be paid to the selection of a pumping head which is massively built, in which there are substantial guides and a babbitted cross-head, all bearings should be babbitt- or brass-lined and those machines should be given preference which do not have overhanging bearings, and in which the gear teeth are cut rather than cast. Such attention to details of construction will mean very much more reliable machines, and one in which stoppages for hot boxes and repairs will be much less frequent, although of course the first cost of the machine is going to be higher than the machine in which not so much attention is paid to the refinements mentioned.

With this type of plant, the capacity is so relatively small, even in the largest sizes, that it will be found that a reservoir is an absolute essential to its successful use in irrigation.

CHAPTER X

COST OF PUMPING

Importance of Knowledge of Pumping Costs.—The matter which most immediately interests, or should interest, the man who expects to take up the practice of irrigation by pumping, is that of cost, and it is upon this point particularly that he should take special pains to become thoroughly and reliably informed. There are, unfortunately, too many projects now in the West which probably would never have been carried through had the owners been careful to acquaint themselves beforehand with reliable information from unprejudiced sources on the various details of cost.

Plant Owners' Statements Unreliable.—It might be said at this point that the prospective pumping-plant owner will do well to accept with some reservations the statements of the owners of existing plants, both as to the cost of operation and the capacity of their plants. Since many, if not most, of such plants are the product of the owner's labor and thought, he is bound to have a certain pride in his achievement which blinds him to its faults and leads him to entertain a possibly sincere conviction that his only pumping expense or charge is for power, that he uses less of this as compared with the amount of water pumped than any of his neighbors, and usually also makes him, when in public, estimate the capacity of his plant at just about double what an actual measurement will show it to be. There has long been a need for some authoritative tests to determine the actual cost of pumping and although a

beginning has been made in the matter by several investigators, including the writer, there yet remains much to be done before reasonably reliable estimates are possible for a given set of conditions.

Factors Affecting Cost of Pumping.—The cost of pumping depends upon the following factors:

(1) Cost of Power, which involves—
   (a) The quantity of water pumped.
   (b) The total head through which this quantity is pumped.
   (c) Efficiency of pump.
   (d) Efficiency of transmission of power between engine or motor and pump.
   (e) Cost of steam, gasoline, distillates, or electricity.
(2) Interest on first cost of plant, and depreciation.
(3) Maintenance and repairs.
(4) Attendance.

These several items, numbered 1, 2, 3, 4, enter into the cost accounts of any enterprise involving power or manufacturing a product by the use of power, and should, therefore, enter into the calculations of the man who proposes to run a pumping plant on a businesslike basis. In order that each may be properly understood, the items will be discussed in order.

(1) Cost of Power

Head and Quantity Pumped Determine Power Requirement.—A pump running steadily raises a certain quantity of water through a certain distance every minute. Since each gallon weighs about 8⅓ pounds, the pump lifts a certain weight every minute through a certain height, and consequently performs work just as does a laborer in a

trench who elevates to the surface every minute or two a shovelful of dirt weighing a certain amount. Now, in the case of the laborer, if he throws out larger shovelfuls at the same intervals of time as before, and from the same depth, he is doing more work than before, as is he, also, if he continues to throw out the same sized shovelfuls in the same intervals of time, but from a greater depth. This illustrates the two facts frequently ignored by pump operators, first, that if the quantity of water discharged per minute is increased when the head remains the same, the amount of work done by the pump increases in direct proportion; second, that if the quantity is not changed, but the head increased, the work will be increased in direct proportion. From this it follows that the work done by the pump varies as the product of head times discharge. Consequently, it will require twice as much power and the power cost will be double for a 50-foot head what it would be for a 25-foot head for the same quantity of water pumped. It is of considerable importance, therefore, that prospective pumping-plant operators realize fully the fact that the attempt to pump against a high head jeopardizes their chances of success, since power used up in overcoming head, represents an outlay for which there is no return, whereas power used in increasing the discharge results in greater acreage irrigated and greater profits. It being seen, therefore, that head and capacity are the two factors governing the amount of power required, it is of importance to calculate or estimate closely the probable requirement of the specific design in question. The method of estimating the power requirement is given in Chapter VII, page 86.

The power required being known, it is then in order to estimate the cost of power. This will depend, in turn, upon the type of engine adopted, for it may be said that that engine will or should be used, which under the local con-

ditions will give power most cheaply. Without going into the mechanical details of the machines, which will be discussed elsewhere, it may be said that a choice must be made from the following:

(1) Steam Engines,
(2) Gasoline Engines,
(3) Crude Oil or Distillate Engines,
(4) Producer Gas Engines,
(5) Electric Motors.

The cost of power will now be discussed for each of the several prime movers mentioned, as based upon information from tests made by the writer, and as drawn from sources known to be authoritative, as well as conservative.

Steam.—The cost of power developed in a steam plant varies considerably with the size of the plant. This follows from the fact that the smaller the plant the greater in proportion are the heat losses, due not only to lack of refinement in the details of the equipment, but also to certain physical laws which it is unnecessary to discuss here. The cost of power in a steam plant may be said to depend wholly upon the amount of coal used, since, under most circumstances, the boiler feed water is a minor expense, and may be neglected. In all centrifugal-pump plants an automatic, simple or compound engine should be used, since the rotative speed of the pump being high the engine speed may also be high. Corliss type engines are practically eliminated from consideration in connection with the size of plants which it is the purpose of the author to treat. For very large plants, such as used in the rice belt, Corliss engines are probably economically justifiable. The steam consumption of the automatic high-speed engine will vary from a minimum of 30 pounds delivered horse-power per hour in the larger engines to 50 or 60 pounds in the smaller sizes. The amount

of coal required per delivered horse-power hour of engine and boiler feed pumps will depend not only upon the size of engine, but also upon the size and type of boiler. In the smaller plants the amount of coal burned per delivered horse-power per hour of engine will vary from a maximum of nearly 15 pounds in the small plants, to an average of 8 or 9 pounds in the larger plants below 200 horse-power.

The following diagram shows for different sizes of plants and different prices of coal, the fuel cost per delivered

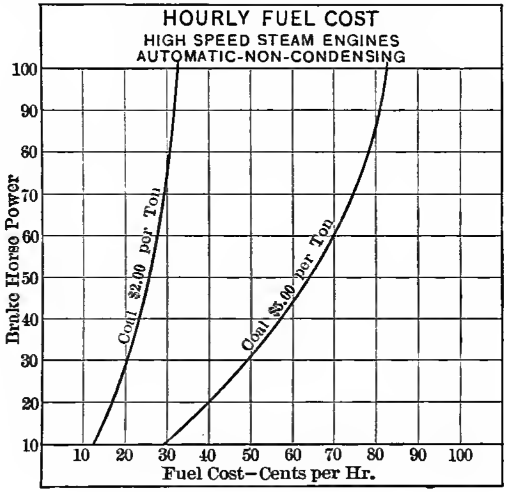


DIAGRAM 19

horse-power hour and the fuel cost per hour of operation. For plants operated but ten hours per day, about 10 per cent. should be added to the values given by the diagram for the standby losses.

This diagram shows the basis upon which a reasonably safe estimate of the cost of power may be based in steam plants of sizes within the limits given by the diagram. To illustrate use of diagram, suppose that it is found, for a

given set of conditions, that an engine capable of delivering 70 horse-power is desired. Following horizontally across to the curve representing the price of coal, the cost per hour in dollars is found vertically beneath on the horizontal scale. The cost per hour for coal at prices different from those of the diagram may be obtained by direct proportion.

Gasoline.—The gasoline engine is most useful in pumping plants requiring less than 30 horse-power. At and

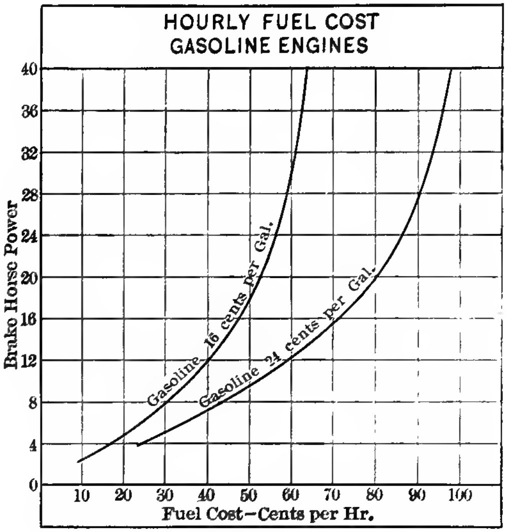


DIAGRAM 20

below that power, it makes the most convenient and cheap, if not always the most reliable power we have. In the hit-and-miss governed gasoline engines, the full-load fuel consumption for an engine in good order varies between about 1 pint of fuel per delivered horse-power per hour in the large engines, to about double that amount in the smallest. The

power cost per hour is shown graphically in Diagram 20 for gasoline costing 16 and 24 cents per gallon.

Crude Oil and Distillates.—Crude oil has not come into use for engines of small power, say below 10 to 15 horsepower, and its combustion is attended by difficulties of so serious a nature that it can only be used in engines of special type which are very much more expensive per horsepower than ordinary internal-combustion engines. Crude oil from the California fields is difficult, if not impossible, to use in such engines without previous distillation, owing to its heavy asphaltum base, but oils from the Texas and Louisiana fields may be and are being used with fair success.

Distillates, that is, oils from which the lighter hydrocarbons, such as gasoline and engine naphthas, etc., have been distilled off, and the heavy bases removed are very commonly used both in special engines and in engines of the ordinary type fitted with special carburetors. Kerosene is rapidly taking the place of gasoline in localities where gasoline is expensive, but kerosene, like other lower-grade distillates, cannot be used in gasoline carburetors. The tremendous growth in the demand for gasoline for use in pleasure and commercial automobiles, to say nothing of the great number of farm engines, tractors, etc., and its uses in the industries, is doubtless responsible for a rapid increase in its price, so that unless the condition is relieved, it will soon have a very serious effect upon the fuel-cost factor in pumping. One attempt to meet the situation has resulted in the evolution of a new fuel known as "Motor Spirit," which is said to be a combination of gasoline and kerosene and which sells at a few cents under the market price of gasoline. This fuel is claimed to have a higher heating value per pound than gasoline and to have no objectionable qualities as an engine

fuel except a rather pungent odor from the exhaust. The introduction of this fuel is not thought, however, to have any very deterrent effect upon the rise in price of fuel oils in general.

Distillates could, until recently, be purchased at the refineries at about 2¼ cents per gallon F.O.B. in tank-car lots and rarely cost more than 4 cents per gallon at the nearest railroad point in tank-car quantities. The recent advances in crude oil have, however, somewhat increased these prices. Since a gallon of distillate weighs about 7 pounds, it follows that 1 pound of distillate at 4 cents per gallon costs 0.57 cents. The fuel consumption of an oil engine is usually stated in pounds of fuel oil per delivered horse-power per hour rather than in pints or gallons, owing to the variable weight of oil per gallon. The makers of the Hornsby-Akroyd type of engine in this country guarantee a fuel consumption at full load of 1 pound per delivered horse-power per hour. A test of a 17-horse-power engine of an engine of this type at near full load, made by the writer, gave a fuel consumption of 1.10 pounds Solar oil per delivered horse-power per hour. This engine was used for driving a centrifugal pump. It probably is wise to count on a fuel cost of from 0.6 cent to 0.7 cent per delivered horse-power per hour for such fuel in an engine specially designed to use it, with oil at 4 cents per gallon. For oil at greater or less price per gallon than that mentioned the price per horse-power hour would vary accordingly. Crude oil engines of the high pressure or Diesel types, when in first-class condition, will operate on from 0.50 to 0.75 pounds crude oil per hour, but such engines in this country are not made in small sizes, *i.e.*, less than about 125 horse-power.

Producer Gas.—Undoubtedly the cheapest power on earth to-day is producer gas when made in an efficient pro-

ducer and used in an efficient engine. There is no question whatever but that in the gas producer lies the solution of the smoke nuisance and the problem of producing power cheaply from coal. In the course of time, when engines and gas-producing processes have become more perfected, it is doubtful if the steam engine will be used in any enterprise where we have continuous operation. In other cases, also, the gas producer will be used when producer-gas equipment is so far reduced in price as compared with steam equipment of equivalent power that the fuel saved by the producer will more than equal the difference in the fixed charges on the two types of plants. Producer gas may be made from a great variety of materials, among which are anthracite coal, charcoal, coke, bituminous coal, lignite, oak bark, sawmill refuse, or wood of various kinds. Of these, the first three named are the most commonly and successfully used, and those alone, indeed, which it is possible to use satisfactorily in the ordinary suction producer. Although producers for bituminous or soft coal have been devised for commercial use, they are much more complicated, and therefore considerably more costly, than the hard-coal producer. Unfortunately, anthracite similar to that of Pennsylvania is unknown in the Western States, except by importation, and its use is, therefore, out of the question, since it sells for from $6 to $12 or $15 per ton, depending upon the grade. There are some semi-anthracites, however, such as the product of the Cerillos Mines of New Mexico, which it is claimed have been used with considerable success in suction gas-producers and which upon test have been found to yield 1 horse-power hour on 1.5 pounds of coal. This coal may be purchased at not to exceed $7.50 per ton at the nearest railroad point in most parts of New Mexico, Arizona, West Texas, and southern Colorado. In Mexico, mesquite charcoal has been used

successfully, this costing about $10 per ton (gold). Lignites, of which great deposits are found in the Dakotas, have been tried in producers by representatives of the United States Geological Survey with apparently favorable results, though it is not believed that this fuel has been tried commercially to such an extent that much can be said about it so far. The other materials mentioned in the above list are of relatively low heating value per pound, and unless they can be used in the immediate vicinity where found or produced, it is not likely that they are of commercial value as fuels.

Electricity.—As stated previously in discussing the various types of plants, electric power is by far the most convenient when it can be obtained, and plants run by electric current have a further advantage in that cost of attendance is reduced to practically nothing. It may be more expensive than power generated on the premises, although it is not improbable, in some cases where plant owners found electricity bought from a central plant more expensive than the power they could generate themselves by a gasoline engine or some other type of prime mover, that the owner of the plant ran the same himself, and therefore made no charge for attendance, and further that he made no allowance for interest, depreciation, or maintenance, basing his inference entirely upon fuel cost.

It is customary for companies supplying electrical power to base their tariffs upon a certain monthly charge based upon the size of the motor, which must be paid regardless of whether the machine is or is not used. This charge may vary, say, from $1 to $2 per horse-power per month, and is justified upon the grounds that the company must maintain a certain equipment ready to supply this power whenever needed, and since this equipment is subject to interest and depreciation charges it is reasonable that the customer

should share this expense. In addition to this fixed charge, there is a power charge which varies according to a sliding scale, the greater the number of kilowatt hours used, the less being the charge per kilowatt hour. This may vary from as much as 7 cents per kilowatt hour to as low as 2 cents. Another method is to have a minimum and a maximum charge per kilowatt hour. Thus, say, for below 500 kilowatt hours per month it might be 5 cents per kilowatt hour, but above 500 kilowatt hours per month it might be 3 cents per kilowatt hour. In addition to this would also be added the monthly fixed charge based upon the size of the motor.

In some cases with a pumping load and for plants of above 25 horse-power capacity, the charge is based upon a certain amount per horse-power, as determined from a peak load indicated by a graphic or curve-drawing wattmeter. The writer knows of contracts where the power charge for the season is $20 per horse-power upon a seasonal half-hour peak, the season being five months, and of others with a charge of $4 to $5 per horse-power per month upon a monthly peak of one hour. Such contracts are drawn up with the object of protecting the power company against excessive peak loads in large pumping plants with many units, and are supposed to encourage the plant operator to exercise judgment and discretion in the use of power. Peak-load contracts are, however, not at all justifiable in plants of only one or two units and they lead to much trouble and misunderstanding unless the power company furnishing alternating current is prepared to maintain a very uniform frequency and voltage. Power consumers entering into such contracts should install in their plants their own graphic frequency meters, by which they can ascertain if high seasonal or monthly peak loads are coincident with periods of high frequency. If such be the

case, there is considerable reason to believe that the peak load is due as much to poor operating conditions in the generating plants of the power company as to excessive load conditions in the pumping plant, due consideration being given, of course, to changes of head and to régime of pumping machinery.

Still another method of charging for electrical service is known as the "flat rate." This varies from $20 to $40 per rated horse-power of motor for a season of five months. The amount charged varies according to locality and is usually based on a sliding scale, the larger the motor the less the rate. Where pumps are operated continuously and the motors are loaded up to their rating, this often proves the most satisfactory, both for consumer and power company. The figures given will vary widely with different companies, depending upon the size of the central station, upon whether it is hydraulic or steam, and, if the latter, the cost of coal.

(2) Interest on First Cost of Plant and Depreciation

It is very rarely, indeed, that the practical operator of a pumping plant considers interest and depreciation in with the cost of fuel as contributing to the total cost of pumping, the reason for this being, probably, that they do not appear as evident an outlay as the fuel bill. A moment's reflection, however, should make it apparent that the farmer who owns a pumping plant has invested in it a certain capital which he may have borrowed and upon which he may be paying current rates of interest, or it may be that he has tied up in the pumping plant certain savings which otherwise might be loaned at local rates. However this may be, it is certainly a good principle to figure interest at current rates upon the cost of the plant and add to this the cost of fuel, etc., since the pumping plant must earn this interest

and enough to pay for fuel, otherwise it is certainly a poor investment. In other words, good accounting would suggest that the pumping plant be credited with the amount of water it produces at the value of this water either upon the farm to which it belongs, or upon its value if sold to surrounding farms at current water rates (the matter of water rates being entirely a matter of location, character of crops grown, etc.), and the plant should certainly be debited with the cost of production of this water. The cost of production will include fuel and supplies, repairs, attendance, interest, and, possibly, depreciation. If, at the end of a year, a balancing of the ledger shows that the plant has not produced enough water of sufficient value to cover these items, then it is a business failure. It may, of course, be changed in certain respects, where experience has shown that defects interfering with its reliable or efficient operation exist, but if the plant is as reliable as others of its kind, then the best thing to do is to sell the plant for what it will bring.

Depreciation has been mentioned in the above as a possibility, since it depends upon whether the pumping-plant owner regards the plant as "a going concern" or an experiment. If he regards it as the latter, then it is not a permanent improvement or asset, and no thought need be given to its renewal after it is worn out. If, on the other hand, it is to be regarded as a necessary appurtenance to the land and as something which gives to the farm its value, then it is wise to make immediate provision against the time when it will be consigned to the junk heap and a new equipment installed. This means, then, that in addition to paying for fuel, supplies, repairs, attendance, and interest on first cost, it should earn yearly such a sum as will, when put at interest, have accumulated at the end of such time as it may be expected the plant will last, a sum that will be

sufficient to pay for a new plant. It will be seen that it is a difficult matter to estimate the yearly sum which should be set aside, since, in the first place, it is a problem in annuities and compound interest, and, in the second place, it is very difficult to tell just how long the plant will last. In other words, what number of years is it reasonable to assume must elapse before the plant is so badly worn out that it will be cheaper to replace it entirely than to attempt to repair it? The problem is rendered all the more difficult, since not all parts of the plant will depreciate uniformly. Thus the probable life of a boiler is about fifteen years; of a steam engine, ten years; of a gas, gasoline, or distillate engine, eight years; of a cheap centrifugal pump, five years (unless the water is unusually free from sand, when it might easily be double that); rubber belting, three years, leather belting, five years; reciprocating leather-packed, rubber valve pumps, five years; deep-well ball-valve pumps, five years; wooden curbing and well timbers, five to seven years. Exceptionally good operating conditions and intelligent care may increase the above periods by double in the case of high-grade pumps, and for plants in use but a month or two out of the year the depreciation may be very slight, if the machinery is properly housed, covered, and greased while idle. The above periods may be taken as a basis, however, and either the depreciation figured on each item separately or the depreciation charge based upon the plant as a whole. In general, ten to twelve years will be the life of the plant as a whole, except in the case of electrically driven very high-grade plants, which with proper care should have a life of 25 years at least.

The following table abstracted from Kent's Handbook shows the sum which must be put away at the end of each year at various rates of interest to accumulate $1,000 at the end of different intervals of time.

DEPRECIATION TABLE

Years to Run	Rate of Interest, Compounded Annually		
	3 per cent.	4 per cent.	6 per cent.
5	$188.35	$184.63	$177.39
7	130.51	126.61	119.13
8	112.46	108.53	101.03
10	87.24	83.29	75.87
15	53.77	49.94	42.96

As an illustration, suppose that in a district where money may be compounded at 4 per cent. annually, a pumping plant costs $2,500. Then for an estimated depreciation period of ten years there should be added to the yearly cost of operation account 2.5 × $83.29 = $208.22. If at the end of each year this sum is placed in a bank on time deposit at 4 per cent., it will at the end of ten years amount to the original cost of the plant. This scheme, known as an amortization or depreciation account is regularly adopted and followed by business firms employing machinery subject to wear and tear, and it is certainly worthy of being imitated by the man who regards a pumping plant as a business proposition and not as an experiment or plaything.

In the above illustration it will be noted that the depreciation is about 8⅓ per cent., and if the prevailing rate of interest in a locality on real estate is, say, 8 per cent., then 16⅓ per cent. of the original cost of the plant must be earned by it annually in addition to fuel and other items of expense in order that it may be considered a financial success.

(3) Maintenance and Repairs

In every plant, of whatever description, there are things constantly needing to be replaced or purchased new, and

even in the best plants small repairs will need be made from time to time. Thus in gasoline-engine plants, batteries will need replacing, spark plugs will become short-circuited, valves may warp beyond possibility of grinding, and need replacing, etc., while in a steam plant valves must be re-seated, gaskets replaced, leaky boiler tubes repaired, etc. Then occasionally some carelessness in operation may result in a ruined bearing, a cracked cylinder jacket, and so on. All such repairs and replacements must be charged against the plant and enter into the cost of operation, for they will occur from year to year and no plant is free from them. The same is true of such items as waste, lubricating oil, etc. None of these items of expense can be neglected by the man who really desires to know how much it costs to pump water.

(4) Attendance

An oil-engine plant (distillate or gasoline), when in good condition, requires a relatively small amount of attention, although it is scarcely true, as some engine manufacturers claim, that such a plant can be started in the morning and require no further attention till it is shut off at night. While this may be true in theory, the practical operator finds that a gasoline or distillate plant requires from one-third to one-fourth of a man's time, when including in the course of a season all those vexatious little delays due to faulty ignition, choked or wet carburetor, hot boxes, etc.

For a steam plant or producer-gas plant, the constant attendance of a more or less skilled man is required during the entire season of pumping, and in a large plant the man will need the occasional services of one or more helpers.

Pumps driven by synchronous or induction motors of under 25 to 40 horse-power will need very little attention except an occasional oiling and possibly replacement of

packing. Larger plants up to 500 horse-power, these being in general those which pump from surface sources, will require a regular attendant who may, however, also act in many cases as ditch rider and water master. Plants above 500 horse-power will require the constant services of a skillful operator and a night helper in case of 24 hours' operation. The matter of skilled attendance is a most difficult one for large electrical pumping plants, since the season is usually only five months, and it is impossible to secure the services of really capable operators for merely that length of time. Much of the success of these projects will depend upon the management being able to provide 12 months' employment at an attractive salary for men able to operate the pumping machinery on an efficient basis and maintain it in the best condition for reliable operation.

It is evident, therefore, that to the cost of power, interest and depreciation, maintenance and repairs, there is still another item of importance to be added in order to arrive at the true cost of pumping. If a man is employed as attendant who devotes a portion of his time to the care of the plant, the total number of hours during the pumping season when he is so occupied should be kept recorded and the proportional part of his season's pay charged against the plant.

In case the owner of the plant attends to it himself, his natural tendency is to regard the charge for attendance as nil. This is fallacious, however, for the time so occupied might be given to other equally or perhaps more profitable work. If possible, therefore, the owner should estimate the number of hours devoted to the plant during the season and charge it up at the same hourly rate as would be paid competent help hired for the purpose.

CHAPTER XI

THE QUESTION OF COST AND PROFIT ON A SMALL FARM IRRIGATED BY PUMPED WATER

Elements of the Problem.—The most vital question confronting every individual, whether he be an irrigation farmer considering the advisability of building a pumping plant or a business man venturing upon an enterprise of any sort, is whether the project will pay. This question is paramount to any question of design, installation, or operation, but unfortunately it involves in its consideration and solution more or less definite knowledge on each of these three points since, until some definite figures are available on the actual cost of obtaining water, one very essential element in the problem is lacking. For this reason, therefore, a consideration of the question of cost and profit has been deferred until amounts of water needed and types of plants to secure this water could be discussed and some better idea secured, perhaps, of those elements which enter into the cost of water. The latter, it must be recognized, is, however, only one of a number of elements which determine the feasibility of a project from the financial standpoint, and preliminary estimates, which are to determine whether there is a reasonable expectation of profit, should, also, involve the following:

First—*A Fair Estimate of Yields.*—This should not be based upon any exaggerated idea of the fertility or richness of the soil, or upon results secured, possibly, by some farmer of the district who, by unremitting toil, fertilizers, and special knowledge and methods, has secured phenomenal returns from an acre or two of ground. Neither should one swing to the other extreme and take as representative

the results of the less skillful farmers or those who through lack of water, unskillful cultivation, or insect or rabbit depredations made little or no crops. The endeavor should be made to gauge as nearly as may be the average crop-producing ability of the land when given intelligent care and attention, and taking results over a series of years if such information be available. Care and discrimination are often necessary when crop information for the exact locality is not available, in projecting such data for other districts than the one in question, for although climatic and soil conditions, altitude, etc., may be thought exactly the same, it is frequently found that the productive capacity is widely different.

SECOND—*The Cost of Crop Production.*—This will include all those expenses incident to the growth and harvesting of the crop, and are fairly well defined and understood by those having any practical knowledge of irrigation.

THIRD—*Shipping Costs and Market Rates.*—Both of these items enter into the question of returns, and should not be neglected by the individual who is making a careful study of the possibility of profit. It is a local matter entirely, and is one requiring careful and full investigation. The matter of suitable market and one convenient of access is very largely a determining factor as to whether it will pay to invest in an irrigation scheme, for however cheaply the water may be secured, if it is in a region remote from railroads and suitable markets it is evidently of little use, except, possibly, in the development of a cattle-raising industry.

FOURTH—*Money Rates.—Labor Conditions.—Cost of Materials.*—That these are also involved in any local set of conditions, and will enter directly or indirectly into the whole problem of cost and profit, is too evident to need emphasis or discussion.

Demonstration of a Problem in Cost and Profit.—To demonstrate a consideration of the problem, a tract of 20 acres will be assumed in a locality where alfalfa, grains, melons, truck crops, and orchard fruits (not citrus) may be grown. It will be assumed, for convenience, that it is proposed to drive the pumping plant by electric current, although, of course, the kind of power used might be gasoline or steam engine, and the method of attacking the problem would be the same. The type of plant is that shown in Fig. 26 (Page 119), and its capacity will be taken at 300 g.p.m. The cost of such a plant for various total lifts (static, suction, and friction head) is shown by the accompanying diagram. The costs given are based on

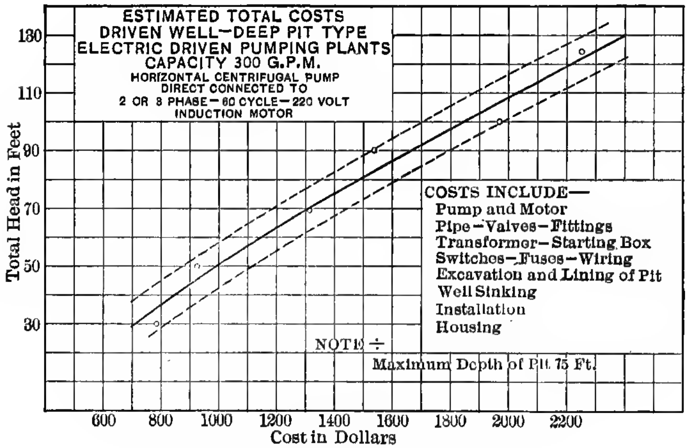


DIAGRAM 21

actual quotations of machinery jobbers, and include estimated freight charges for 100 miles and labor in erection. The cost of a 3-phase 60-cycle 220-volt motor and starting box is also included.

Assuming that 30 acre-inches will be required by the tract per season (this including all distribution losses), it will be found that the plant must operate about 900 hours. Estimating the energy cost at 3½ cents per kilowatt hour (in advance of more exact knowledge of cost of power when total power requirements for a given project are known), and allowing an interest charge of 8 per cent. and depreciation, taxes, etc., of 8 per cent., we find that the total fixed and operating charges of an electric-driven pumping plant are as shown in Diagram 22.

With the operating and fixed charges known, the prob-

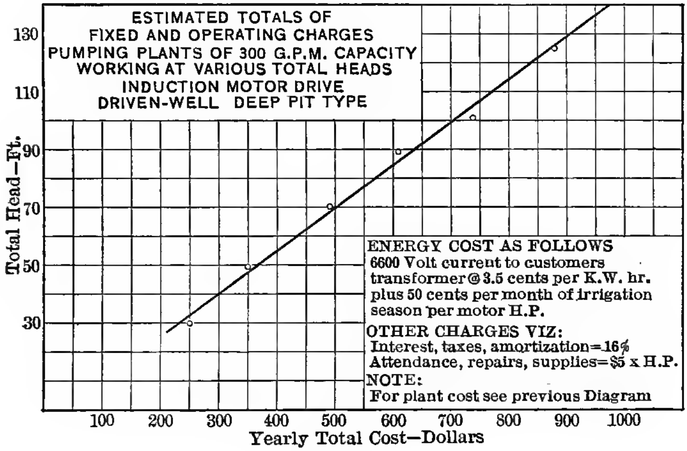


DIAGRAM 22

able returns may be calculated. The table on page 156 shows the basis of estimate of net returns on various crops.

A farm of 20 acres was selected as representing probably the limiting size for a man of average means starting in a new country. The division of this acreage for the first few years is a matter upon which considerable difference of opinion may arise. Some would doubtless attempt a large

TABLE IX

SHOWING ASSUMED YIELDS AND PROFITS

Crop.	Yield per Acre.	Market Value.	Total Gross Return per Acre.	Net Return per Acre.[1]	Value of Land and Improvement.[2]	Interest and Taxes on Land and Improvements.	Return per Acre After Deducting Interest and Taxes.[3]
Alfalfa	5 tons	$10 per ton	$50.00	$25	$150	$16.50	$8.50
		15 per ton	75.00	50	150	16.50	33.50
		20 per ton	100.00	75	150	16.50	58.50
Wheat	40 bush.	$1 per bush.	40.00	32	100	11.00	21.00
Oats	60 bush.	2c. per lb.	38.40	30	100	11.00	19.00
Corn, Grain	40 bush.	1 1/2c. per lb.	33.60	35	...	......	......
Corn, Fodder	4 tons	$4 per ton	16.00	...	100	11.00	24.00
Orchard fruits[4]	....	....	......	300	600	66.00	234.00
Truck garden or melons	....	....	......	100	400	44.00	56.00

[1] These values are based upon the average cost of seeding, cultivating, harvesting, and labor in irrigating a crop, but do not include cost of water.

[2] Improvements are considered such measures as are necessary for the convenient and proper irrigation of the land, and will vary in cost from $15 to $50 per acre, depending upon the original character and topography of the land.

[3] From these values must still be deducted the cost of water, based upon fuel cost and other expenses of pumping, in order to give net profit. These figures are to be compared with those under total yearly expenses in Diagram 23.

[4] These include apples, pears, and peaches. The returns and land values are based upon conditions in the more successful fruit-growing districts of the West.

acreage of truck garden or orchard, but the general experience is that it is well for several years to have at least half of the small farm in alfalfa, which quickly comes to maturity and provides a profitable crop requiring but little labor, and enriching the soil so that later it will be available for orchard and truck crops if it is desirable to increase the acreage given over to them. The latter, however, while more profitable than alfalfa, are at the same time much less certain, being more subject to the effects of frost and to the ravages of insect pests and rabbits. They also require a very considerable amount of labor in production and harvesting, and consequently are crops which should be attempted only on a small scale, except after many years' experience, and upon a co-operative growing, picking, and selling basis with the other producers. Onions, for instance, have been found very productive and profitable under irrigation in the Southwest, $500 profit per acre having been reported, but it must not be forgotten that one acre will require almost the entire time of at least one man, and often two, in properly caring for the crop in order that so large a profit may be secured. Consequently, the acreage which may be cared for by the individual grower during the first years of his efforts must necessarily be limited. The same is true of melons and other crops giving large returns per acre. We will, therefore, assume that the 20-acre tract is divided thus: 10 acres in alfalfa, 5 acres in orchard, 2 acres in onions, 2 acres in melons, 1 acre in roads, buildings, etc.

Using the above table of estimated yields and net returns, we see that the total net return may be as follows:

	A	B	C
10 acres alfalfa	$85	$335	$585
5 acres orchard	170	670	1,170
2 acres melons	112	212	312
2 acres onions	112	212	312
Profit	$479	$1,429	$2,379

These figures are based upon the following values:

	A	B	C
Alfalfa per ton............	$10	$15	$20
Orchard net return per acre.	100	200	300
Melons and truck products per acre..............	100	150	200

The net profits in the above table have not taken into account the cost of water, but, as will be noted above, the interest on value of land and improvements and costs of production have been taken account of and allowed for. If, therefore, the fixed and operating charges on the pumping plant are compared with these values, the growers' net profit may be determined. By Diagram 22 we have an answer finally to the question which is of first importance when considering a pumping project, whether individual or communistic, this question being, "From what depth will it pay to pump water for irrigation purposes?" As will be seen by reference to Diagram 22, when the total head exceeds 65 feet, if prices correspond to condition A there will be no profit whatever, the cost of running the pumping plant swallowing up the profits on the farm. For condition B, however, there is some profit up to probably 150 feet, and for condition C there is profit at almost any head within the practicable limits of mechanical operation of pumps. A means of determining the approximate net profit above all interest, depreciation, and production charges is given by the Diagram 22. Thus let us assume that the total head is to be 50 feet and that the condition B is supposed to prevail. By referring to the figure it will be seen that the net profit is about $1,052. In closing the discussion of this matter, it may be remarked that the problem is not possible of general solution and must be considered with special reference to local conditions and to reasonable assumptions on the following points:

1. The size of tract desirable for the individual farmer of average means to attempt to irrigate by pumping.

2. The size of pumping plant necessary for this acreage.

3. Reasonable assumptions as to yields, cost of production, and market prices.

It is to be also noted, since the chances for profit at a given head are further reduced by a pumping plant of excessive size for the given acreage, that in such estimates careful attention be paid to the selection of the proper size of plant. Some light on this matter may be derived from the following list of plants in operation, with which the writer is personally familiar, and the acreage irrigated by each.

	Capacity. Gallons per min.	Acreage.
Plant 1	800	120
Plant 2	375	40
Plant 3	265	20
Plant 4	350	40

In some localities it is customary to allow 700 gallons per minute per 100 acres.

It will be noted, from the diagram of fixed charges and operating expense of pumping plant, that if the crop is wholly alfalfa there is no profit, however small the lift, when hay sells for $10 per ton, but that at $15 and $20 per ton one could pump through total lifts of 45 and 85 feet, respectively, and still come out even; consequently, at less depths there will be a small profit after all interest charges, etc., have been met.

CHAPTER XII

RESERVOIRS

Their Necessity.—It seldom requires more than one season's experience with a pumping plant to convince the operator or owner that a reservoir in connection with an individual plant is an eminently desirable, if not necessary, adjunct. The pumping plant, which will operate day in and day out through the entire season without some serious difficulty arising, has not yet been built, and these difficulties, frequently causing a shut-down for several days or a week at a time, quite invariably occur when the crop is in most need of water. A shut-down at such a time, particularly with garden crops or melons, may mean the loss of the crop and it is highly important, therefore, that there be some reserve supply of water against such emergencies. There are also other arguments in favor of the reservoir, among which is the fact that by means of a reservoir it is possible to make use of a greater "head" of water when irrigating than is yielded by the pumping plant, since the discharge of the pump for several hours may be retained by the reservoir and then rapidly drawn off through a good-sized ditch to the point of use. By so doing, it is possible to cover a larger amount of land with the same quantity of water than would be possible with a small stream, a fact which every practical irrigator recognizes. Moreover, by the use of a reservoir, it is possible to irrigate profitably a much larger area with a small plant than would otherwise be possible, since the plant may pump water into the reservoir in the night-time and in intervals between irrigations, reducing in this way the stand-by expenses or

length of time during the year that the large plant would be idle, and during which time interest charges on the plant and depreciation keep accumulating the same as though it were in operation. A reservoir suitable for the purpose should not be an expensive piece of work, particularly in a region where clay or adobe soils may be encountered.

Water-tightness.—The chief consideration, of course, next to safety, is water-tightness, but by the use of straw or manure on an adobe bottom and banks, and trampling or puddling thoroughly while wet by driving sheep or goats about the basin, a very compact and water-tight surface may be secured. Pigs are equally effective, if allowed to wallow in the reservoir when it is nearly dry, and a vigorous and sufficiently long-continued tramping by men provided with rubber boots will frequently work wonders in preventing seepage. Where adobe or clay is not found on the site, it will pay to bring it from a distance and spread a layer 6 to 8 inches thick over the bottom and sides, mix it with water, and puddle as above described. The use of oil, California crude, spread over the inner surface of the reservoir in the proportion of about 2 gallons per square yard, will make a comparatively water-tight surface, even in light material, and, of course, if the expense can be borne, a concrete lining not less than 4 inches thick is to be recommended. This will cost from 8 cents to 12 cents per square foot, depending upon locality.

Construction.—A reservoir 100 feet in diameter to contain 4 feet of water may be built with plows and Fresno scrapers for from $150 to $300 complete with suitable outlet. Many have actually been built considerably under the latter amount. The bottom of the reservoir should, of course, be level with the surrounding ground in most cases, to enable water to be drawn down quite to the bottom, consequently the material in the embankment should be

borrowed from outside. This material should not, however, be taken from a point nearer than 10 feet from the outer toe of the embankment, and the borrow pit should be made as shallow as possible.

Previous to building the embankment it is frequently a good idea to plow the surface to be covered by the embankment which should, so far as possible, be built in horizontal

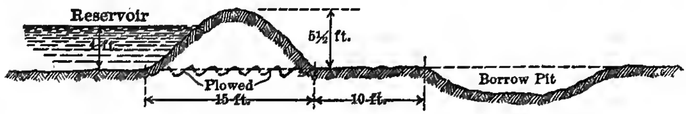


FIG. 32.—A safe method of making an embankment for a shallow reservoir.

layers rather than by dumping over the end, as in a railroad embankment. It should be built not less than 1 foot higher than the proposed depth of water in the reservoir, and its width at the base should be from 3 to 4 times its height. The horses and scrapers should travel along the embankment as much as possible while it is being built, in order to compact or tramp down the material; and a roller, if one is available, will be very effective in breaking up clods and making the embankment tight.

Rodents.—A great difficulty and annoyance with a reservoir are the breaks due to the burrowing of gophers and other rodents. This difficulty was solved in one conspicuous instance in the writer's knowledge by enclosing within the embankment at about the middle a wire netting of galvanized chicken wire fencing of fine mesh which reached vertically from the top of the embankment to the bottom. This serves to prevent rodents from making holes entirely through the embankment, and while adding considerably to the first cost, will doubtless save many times its cost in preventing disastrous breaks.

Capacity.—As to the capacity which should be pro-

vided in a reservoir, little can be said further than that it is mostly a matter of judgment. The larger the reservoir, the smaller, within certain limits, need be the pumping plant, but a large reservoir means heavy losses from evaporation and seepage. A safe rule to follow is to provide sufficient storage for one irrigation of the most tender crop. Thus, if among other crops melons are being grown, this would undoubtedly be the crop most susceptible to drouth and should be provided for. If, for example, 5 acres are in this crop, 20 acre-inches should be stored which is 1⅔ acre-feet. Allowing for seepage and evaporation, it would probably be well to store at least 2 acre-feet for the irrigation of this crop.

Depth.—In general, it is advisable not to build too shallow a reservoir, since this means large water surface compared with the capacity, and evaporation losses are greatly increased as the surface exposed to wind and sun is increased. A depth of 4 feet should probably be regarded the minimum, but the difficulties in the building of a safe and water-tight embankment will, in general, prevent the adoption of a depth greater than 6 feet. The following diagram shows the diameter of circular reservoirs required to hold different quantities of water with a depth of 3, 4, and 5 feet, as well as the number of cubic yards in the embankment and the number of hours required to fill the reservoir by a pump of 500-gallon capacity.

The embankments upon which the diagram is based are represented in cross-section on the diagram. They are a somewhat heavier embankment section than is customary practice. It is usual to make the bottom width about three times the height. This, however, gives side slopes which are much too steep for a safe and lasting embankment.

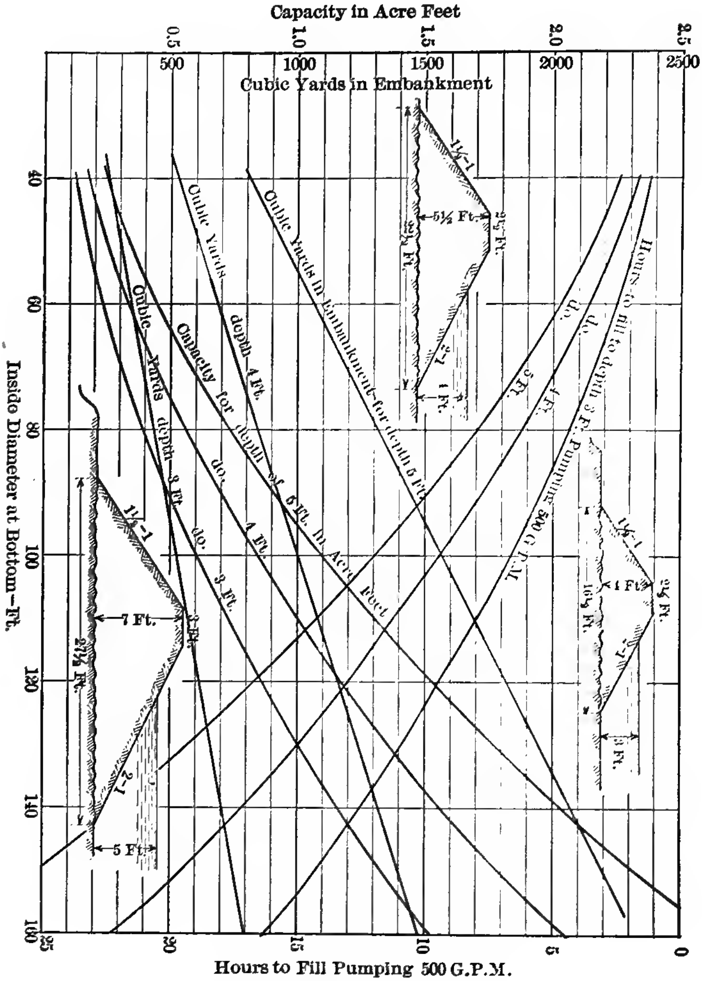


DIAGRAM 23

Cubic Yards in Embankment, Capacity and Time of Filling of Small Circular Reservoirs

CHAPTER XIII

PRIME MOVERS

Steam Engines and Boilers.—With no other prime mover does fuel economy depend so much on the type and size of engine as in the case of steam machinery. In internal combustion engines, the amount of fuel used per developed horse-power hour in the smallest and cheapest engine is not likely to exceed double that found necessary for the largest. In the steam engine, on the other hand, the smaller and less-refined types are apt to use over three times as much steam as those of greater power and more refinement in design and construction. Since saving in steam means saving in coal, it is obviously of advantage to use an engine whose steam consumption is low. This, however, means an engine whose cost is much greater than the other, so that the question is likely to resolve itself into a balancing of interest charges against fuel saving. There are, in general, two classes of engines in the sizes necessary for pumping-plant service which are suitable, namely, the throttle-governed type and the automatic type, both being in the class of so-called high-speed engines. The Corliss engine, though of high economy in the larger sizes, is not so advantageous in this respect in the smaller powers, besides which it is slow speed and per horse-power costs more than the high-speed engine. In the rice irrigation districts, where several hundred horse-power may be used in pumping in one plant, the Corliss type of engine is economically justifiable, but in irrigation pumping in the arid West there will seldom be found a proper field for the use of this engine except in central stations and in certain cases where large

amounts of water will be pumped at some one point from an open water source.

Throttle-Governed Engines.—This type is the cheapest per horse-power and the least economical in steam consumption and should not be used in irrigation pumping in sizes over 15 horse-power. This type is distinguished by the fly-ball governor which acts upon a valve in the steam line between the engine throttle and the steam chest. The governor is usually driven by a belt from the main shaft. Such an engine is likely to use as much as 65 pounds of steam per delivered horse-power hour, and such engine should, in general, therefore, be connected to a boiler rated at least double the engine horse-power. It is very common to drive such an engine by a boiler of the locomotive type, either portable or on skids, and not infrequently the engine is mounted either upon the boiler, or beneath the same, and bolted down to the skids. It is advisable, in general, to use the separately mounted engine, since the stresses on the boiler shell are less severe. This type of engine and boiler, while comparatively wasteful of steam, is both cheap and reliable, and a very good plant to use where steam coal is not over $3.00 per ton, delivered, and the power desired is not over 15 horse-power.

Fly-Wheel Governor Engines.—The other type of high-speed engines, which are made in sizes from 20 horse-power up to many hundreds of horse-power, is distinguished by having the governor in the fly-wheel, which acts upon the valve mechanism in such a way as to vary the point of cut-off. In this way, use may be made of the expansive force of steam, and the engine is inherently more economical of steam than the throttle-governed type. In sizes up to 50 horse-power this type of engine will use about 40 pounds of steam per delivered horse-power per hour, and probably 30 or less for sizes above 50 horse-power.

The boiler capacity for the smaller sizes should, therefore, be from 1⅓ to 1½ larger than the engine horse-power, while above 50 horse-power the rated boiler capacity might be of approximately the engine horse-power.

Boilers.—Up to 60-boiler horse-power, we believe that no mistake will be made in using a semi-portable locomotive-type boiler with water front and open bottom. These boilers require no setting, come provided with their own stack, are good steamers, and are easily cared for. Above 60 horse-power, probably it is better, in a plant that is intended to be more or less permanent, to use a horizontal return tubular, or what is sometimes called a fire-tube boiler. Such boilers are easily handled in construction, and are to be regarded as somewhat safer than the locomotive-type boiler. They require a brick setting, however, and a steel or brick stack. The boiler itself is cheaper than a locomotive-type boiler of the same size, but the setting required brings the final cost as installed to above the locomotive type. The working pressure to be carried by such boilers should not be less than 100 pounds per square inch, and when purchased, the purchaser should see that a reliable safety valve set for this pressure is provided. Water-tube boilers, of which there are a great variety on the market, are undoubtedly safer than either of the types just mentioned. They are intended for service in which there may be sudden and wide variations in the steam demand (as in street railway or general power-plant service), and are therefore not necessary in a plant wherein the load is quite uniform. They are considerably more costly than fire-tube boilers and the setting is likewise more costly. It is doubtful if their use is justifiable in plants developing less than 200 horse-power, which is about the minimum size in which most of them are manufactured.

Auxiliaries and Fittings.—In large plants it will usually

pay to put in a surface or jet condenser, using the water pumped to act as the cooling medium, but in a small plant, or say in one of less than 100 horse-power, the extra cost of the condensing apparatus will scarcely be warranted by the saving in fuel. An efficient steam separator should be used in the steam line between the boiler and engine, and in any plant above 20 horse-power a boiler steam pump should be provided in addition to the injector usually furnished with the locomotive-type boiler. In plants of above 50 horse-power the injector is rarely used at all, and it is a measure of safety to provide boiler steam pumps in duplicate. The boiler and engine should be placed as closely adjacent to each other as possible to avoid heat losses by radiation in long steam pipes, and it will be found not very expensive to lag the steam piping with effective asbestos covering, which may be purchased in molded form ready for application both to pipe and fittings. Steam engines of the types above mentioned should, if possible, be provided with automatic oiling systems, and since engines are often very poorly protected, by the building, from dust and grit, it is better to choose an engine in which the crank and all reciprocating parts are completely enclosed.

Boiler Insurance.—An important matter, to which little or no attention is generally paid by the owners of small steam plants, is that of boiler insurance. A boiler is a potential agent of destruction, and too much attention cannot be paid not only to its proper operation, but to the detection of dangerous flaws and defects, which may result in serious disaster under the best conditions of operation. The services of expert boiler inspectors are obtained when boiler insurance is carried, and it is always worth the trifling expense involved. Those purchasing second-hand boilers, should always insist on being furnished, together with the boiler, insurance in some well-known boiler-insurance com-

pany, for at least one year. Such insurance is the best possible recommendation of the condition of the boiler.

Gasoline Engines

This type of prime mover is so common that description is unnecessary. We find manufactured to-

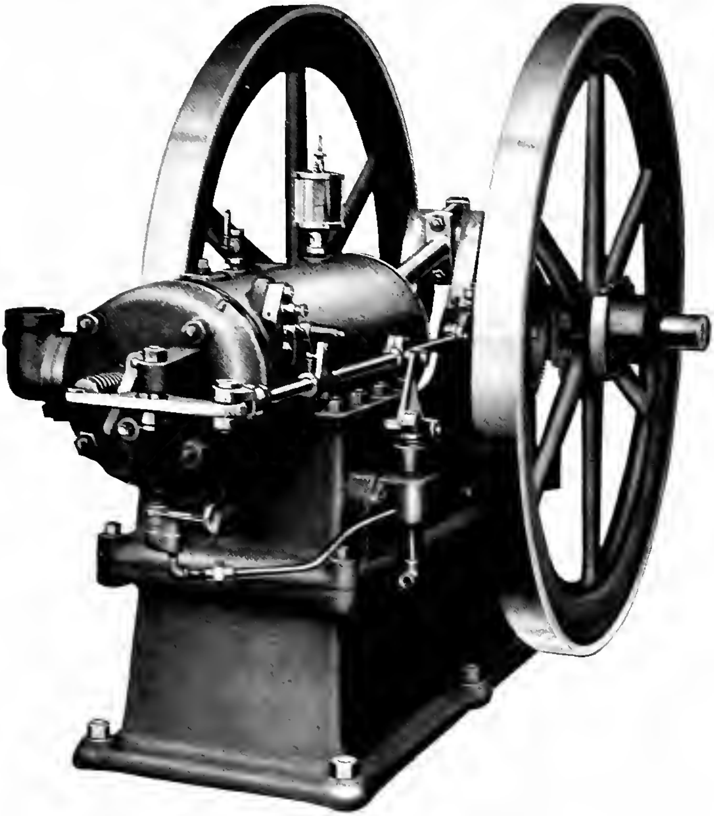


FIG. 33.—An excellent example of hit-and-miss governed gasoline engine suitable for driving pumping machinery.

day a great number of reliable, well-designed engines, such as the Stover, Fairbanks-Morse, International

Harvester, Dempster, and many others, any one of which, with intelligent care and attention, will give satisfactory service.

Difficulties in Operation.—Gasoline engines in general are, however, subject to numerous ailments which are a source of much delay and vexation. In nine cases out of ten, the trouble with a gasoline engine which refuses to run, may be found in the electric ignition or sparking apparatus. The first thing is to see that all binding post thumb-screws are tight on the spark plug, batteries and induction coil, and that the ends of the wires at these points are scraped bright and the binding points are also clean of oil and dirt. The spark plug itself sometimes becomes foul with soot, or the points become so worn that a spark cannot be produced, in which case it should be cleaned or replaced by a new plug, as the case may be. If, after all this has been attended to, a spark still cannot be produced, the trouble probably will be found to lie in worn-out batteries. When a magneto is used instead of batteries after starting, as is a practice always to be recommended, a refusal of the engine to continue running after the batteries are switched off may sometimes be traced to the magneto pulley, which will not keep up to speed because the face of the fly-wheel against which it runs is covered with grease, in which case the remedy is obvious; or the springs in the magneto pulley which force it against the fly-wheel face may have become so weakened that they are unable to force the pulley sufficiently hard against the fly-wheel. If the ignition apparatus has been placed in good condition, further failure to start may be due to troubles in the carburetor or mixing device. Most carburetors are provided with a small orifice through which the gasoline sprays and is mixed with the air, and if this orifice becomes stopped up from any cause, not enough gasoline will be drawn into the cylinder to keep the engine

in operation after the first few explosions, which are usually obtained by pouring a small quantity of gasoline into the cylinder through the pet-cock always provided on top of the cylinder. Sometimes it is impossible to obtain the first explosion by pouring gasoline into the cylinder, which may be due to the fact that an excess of gasoline has been used, which should be removed by turning over the engine several times with the pet-cock and exhaust valve held open, after which a smaller quantity should be tried. Poor gasoline may also cause trouble at starting. Engine naphtha, which is a distillate with a higher boiling point, and which, therefore, does not vaporize as readily as gasoline, is frequently sold to the consumer in place of gasoline, and great difficulty is sometimes experienced in starting, if this is the case. The difficulty may be overcome by using high-grade gasoline for starting and warming up the cylinder, after which the lower-grade oil will vaporize properly and the engine will continue to run, or the naphtha itself may be warmed slightly (much care being employed not to ignite it in so doing), after which it may be squirted into the cylinder and allowed to stand a few moments before the engine is turned over and sparked, the interval of time being necessary to allow the naphtha to evaporate.

Another difficulty may lie in the gasoline pump and valves, which may be leaky, or the suction pipe leading from the fuel tank to the pump may leak air, any one of which will cause the failure of the engine to secure sufficient gasoline and will result in almost immediate stopping. The existence of this trouble may be ascertained by opening up the carburetor, which can usually be done, and operating the pump by hand a few times to see if the gasoline is pumped in good quantity.

Another cause for trouble frequently lies in the suction and exhaust valves, particularly the latter, which may not

be tight, or which may not open or close properly or at the proper position in the stroke. The tightness of the valves and piston rings may be tested by bringing the engine to compression and holding it there. If, after a moment or so, the fly-wheel can easily be forced over the back dead point, it shows that the valves or piston rings are leaky. This may be due to an accumulation of grease or tar on the valve seats or to wearing of the seats, which in the latter case necessitates regrinding by use of an ordinary carpenter's brace and emery dust. Audible knocking in the cylinder and back-firing (an explosion which sends the engine backwards) are always due to the spark occurring at the wrong time. The sparker should for best results trip when the crank is a little below the back dead centre, but care should be exercised not to have this too much. When the centre line of the crank makes an angle of about 10 degrees with the centre line of the cylinder, it is probably in the best position.

A final word is advisable on proper attention to the position of the needle valve on the carburetor, which regulates the flow of gasoline to the cylinder. At starting, this may be quite well opened, but after the load has been put on, the needle valve should be closed to the point at which the engine will just carry the load, or keep up to speed and explode regularly, with an occasional miss. One miss in every ten or twelve explosions shows that the governor is working and the engine probably amply supplied with fuel. The importance of this lies in keeping down the fuel consumption. The writer has frequently been able, by proper adjustment of the needle valve, to very materially reduce the amount of fuel consumed by the engine, in the case of one plant which he was asked to examine, the owner finding that an adjustment of the needle valve reduced the daily fuel consumption from 8 to 5 gallons per day, a reduction in expense of pumping which greatly increased his chances

for profit on the season's crop. A cloud of smoke from the exhaust pipe of a gasoline engine indicates either one of two things, too much gasoline or too much lubricating oil in the cylinder and the remedy is obvious. The circulating water which cools the cylinder should be only so much in

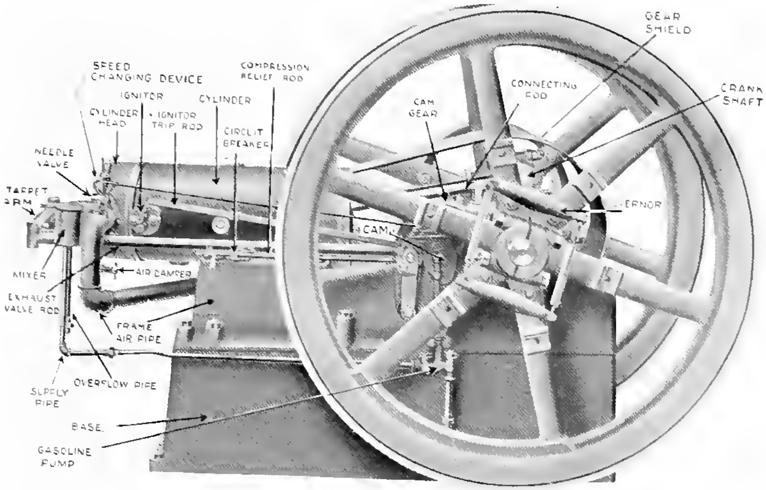


FIG. 33A.—A modern high-grade gasoline engine with parts named.

quantity as will keep the cylinder and jacket cool enough to allow one to keep his hand on the jacket for a moment or so; in other words, the water as it comes from the jacket should be at nearly boiling temperature.

Over-Rating.—A common difficulty with many of the cheaper grades of gasoline engines is that not only are they flimsy and weak in certain parts, but they are over-rated as to horse-power. An engine with a very small cylinder may be made to develop a large horse-power by increasing its speed to far above what would be considered good practice, and this is what is actually done with some of the poorer grades of engines. The speed of an engine

below 6 horse-power should not exceed 300 revolutions per minute, and above that it should decrease from 250 down to 200 or less in the larger engines. The only true way in which to determine the power of engines is by a brake test and all reliable engine manufacturers test in this way each engine made before it is shipped out, to be sure that it will develop its rated horse-power or more.

Oil Fuels.—Gasoline is only one of a great number of products of the distillation of crude petroleum, and it differs from those known as distillates by being lighter and more volatile. The distillates are technically low-graded kerosenes. They have about the same specific gravity, but are not as clear and limpid as kerosene, nor as uniform in specific gravity.

The specific gravity of the various oil-fuel products is by no means fixed, so that gasoline may vary in density through a considerable range and still be called gasoline, and the same is true of other products. There are purchasable, indeed, several grades of gasoline, the lightest being very volatile, and the heaviest being so nearly like kerosene that it is difficult to start an engine when using it, and to use it regularly as a fuel, a carburetor surrounded by a jacket is necessary, through which cooling water from the engine cylinder jacket is allowed to circulate, or sometimes the exhaust gases are so used.

The character of gasoline varies somewhat, also, with the field from which the crude oil from which it has been distilled, has been drawn. Thus, gasoline from the crude oils of the Kansas and Oklahoma fields is most easily used in a gasoline engine when it has a specific gravity of from .753–.745 (58°–60° Baumé); from Texas and California crudes it should have a specific gravity of about .76 (56° Baumé). Gasoline and other oils are classified in commerce with regard to weight usually by the Baumé scale,

so that in buying "60 gasoline" one buys not gasoline of .60 specific gravity, but gasoline which has a gravity of 60° "Baumé," *i.e.*, a specific gravity of 0.745. Much confusion and misunderstanding is apt to result through a common misuse of the term gravity when referring to the "Baumé" scale.

The following table gives an understanding of the distinction between the different grades of fuel oils and the allowable, or distinguishing, range in specific gravity.

TABLE X

Oil	Specific Gravity	Baumé °	Flash Point
Gasoline	.70–70	56–70	....
Engine naphtha	.848	...	....
Kerosene	.80	...	250° F.
Distillates	.91–.88	24–30	100–250° F.
Solar oil	.80	34	....
Crude oils:			
Pennsylvania	.806	43.7	....
West Virginia	.704	40.2	....
Ohio	.804	44.0	....
Oklahoma-Kansas	.851	34.5	....
Texas	.913	23.2	....
California	.964	15.2	....

It will be understood that the distillates vary in "gravity" according to the source of the crude oil from which they are derived, and that the flash point will also vary according to the completeness with which the distillation has been carried on. Distillates with high flash point are safer to store and use than others, since they are less likely to give off inflammable vapors at low temperatures, which become a source of danger from sparks or carelessly disposed-of matches.

Distillate Engines.—The rapidly increasing use of gasoline in automobiles, motor boats, and for other purposes, is

already beginning to be reflected in a rapidly advancing price for this fuel, so that the attention of engine designers and manufacturers has been directed for some time to the problem of utilizing the cheaper grades of fuel oils from crude oil upwards. When an oil of less volatility than gasoline is used in an engine, special means must be taken to secure its proper combustion in the engine cylinder, and the difficulties in accomplishing this increase as the oil increases in density. To overcome these difficulties, special carburetors are sometimes used in which the oil is more or less highly heated in order to increase its volatility and the consequent ease with which it will combine with air to form an explosive mixture, while in other engines the design of the cylinder is so altered from the usual designs as to provide the special conditions necessary for the combustion of heavy oils.

In the first case, carburetors and mixing devices have been devised which will enable the satisfactory use of kerosene and the higher grade of distillates in an engine. The greatest difficulty in such cases is found in getting the engine started on the low-grade oil, and usually means are provided for starting on gasoline and running on it for a short while or until the carbureting device (heated either by exhaust gases or cooling water from engine jacket) has become sufficiently hot to produce the required volatility of the heavy oil, when the gasoline supply is cut off, and the engine continues to operate on the heavy oil.

The writer has seen Solar oil used with entire success in a Fairbanks-Morse engine provided with such a device, the only difficulties being more or less rapid accumulations of tar in the combustion chamber and on the valves and seats, etc. There is also a heavy residual oil formed which either is burned and comes out of the exhaust as a black smoke or escapes by the piston rings and accumu-

lates in the crank case. The presence of this oil in the cylinder obviates the necessity of lubrication, and the accumulation in the crank case has a value as a fuel or lubricant.

When the oil increases in density or its volatility is lessened, the means just described are found inadequate,

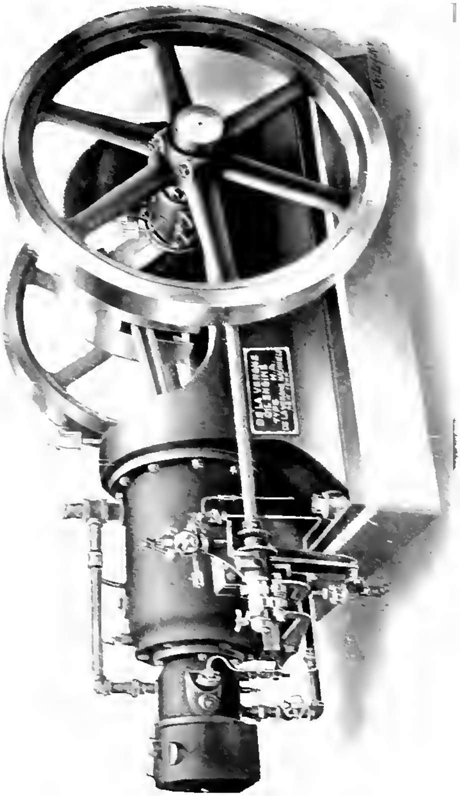


FIG. 34.—An excellent oil engine made in sizes from 12 to 15 horse-power, in single cylinder type and using kerosene, the so-called distillates, and residual fuel oils, 24° Baumé or lighter. Also made in twin cylinder type of 70 and 100 horse-power.

and a special engine must be used. There has been on the market for some years an engine known as the Hornsby-

Akroyd engine (it is now manufactured in this country) which is well adapted to the use of kerosene or the better grades of distillates, such as Solar oil or any oil having a gravity of 24° Baumé or lighter. It will not, however, operate on crude oils. This engine is provided with a vaporizing chamber which is first heated to a red heat by external means and into which the fuel oil is injected and vaporized. On the compression stroke of the engine, air being forced into the vaporizing chamber, combustion results, and is succeeded by a power stroke, exhaust stroke, and air suction stroke similar to any four-stroke cycle engine. After starting, the heat of combustion keeps the vaporizing chamber at the necessary temperature for vaporization and consequently no electric-ignition system is used. A similar principle is used in the Mietz and Weis engine.

No particular difficulty is experienced in the practical operation of these engines except in cold weather, when it is sometimes necessary to warm a heavy oil in order that it may become sufficiently fluid to flow through the pump which injects the oil into the vaporizing chamber. These engines are made in sizes of from 10 to 100 horse-power and offer, therefore, to the owner of the small pumping plant, an extremely economical and very satisfactory prime mover. They cost about 50 per cent. more than a good gasoline engine of the same power.

The Hornsby-Akroyd type engine, when used with heavy oils, soon accumulates a considerable quantity of tarry residues in the vaporizing chamber which interferes with vaporization. This difficulty is surmounted by having several chambers at hand and replacing the one in use by a clean one after 24 or 36 hours of operation. This is a simple operation requiring merely the unscrewing and screwing up again of the nuts on the studs by which the chamber is attached to the main body of the cylinder.

The old head may then be cleaned and made ready again to be placed on the engine.

An engine which has come into great prominence in the past few years because of its remarkable fuel economy,

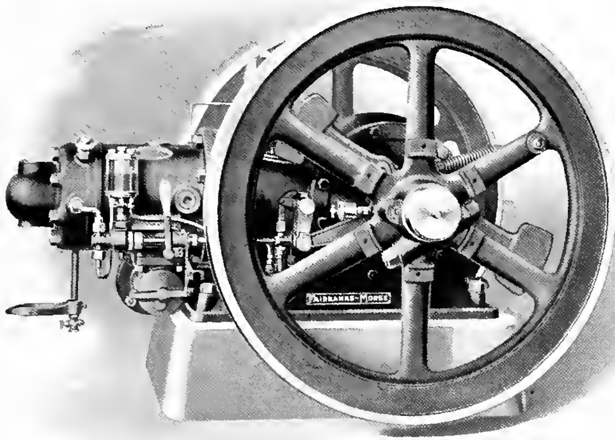


FIG. 35.—An internal combustion engine of about 15 horse-power, designed to utilize kerosene, distillates, Solar oil, etc. Made in a large range of sizes.

is known as the Diesel engine. This is a four-stroke cycle engine of very heavy proportions, due to the extreme pressures realized in the cylinder (600 pounds per square inch or more), and only built (in this country at least) in sizes of over 125 horse-power. It is primarily a crude-oil engine, and will work satisfactorily on any oil not heavier than 19° Baumé, and which does not contain more than 1½ per cent. of water. No electric-ignition system is used, but a component part of the engine is an air compressor for starting and for injection of the fuel. A slightly modified and less heavy engine of this type put out by an

American manufacturer is in successful use in California on the crude oil of that State, with its troublesome asphaltum base. The Diesel engine uses less than 1 pound of oil per horse-power per hour and is destined to have an important future in the Southwest and in California, where oil fuel is abundant and cheap. Its use in relatively small pumping plants is, however, exceedingly questionable in view of the more or less expert attendance required and in view of the fact that it costs about double the price of a gasoline engine or steam plant of equivalent power.

The Gas Producer and Engine.—Principles of Operation.—The elementary action of the gas producer is familiar to all in the example of the ordinary heating stove, which, after being well filled with fresh coal, will sometimes experience a mild explosion due to the formation and ignition of gas. The gas is formed by slow combustion without sufficient draft or air supply to produce complete oxidation or burning of the carbon of the coal. The same principle is made use of in the gas producer in which we have a large retort lined with fire-brick in which coal is burned in the presence of an inadequate air supply, causing the formation of an explosive gas which, however, is caused to explode in an engine cylinder and do useful work in driving forward the piston of the engine. Since the gas formed in the process is used directly and its heating power given out directly in the engine cylinder, it is evidently a much more economical method of using the coal than burning the gases given off by this coal under a boiler, generating steam thereby, which is transmitted a greater or less distance through pipes and finally used in a steam engine. Aside from any questions of practical operation, therefore, it would be apparent to any one that a gas-producer plant would be much more economical in fuel than a steam plant. While the process of generating the gas as above

outlined seems simple, the difficulties in cooling, cleaning, and regulating the gas flow, and of firing, cleaning, and poking the producer, to say nothing of finally utilizing the gas in the engine cylinder, all have to be overcome and solved before the plant can be called a commercial success. Up until the last half-dozen years, the producer plant was a thing to be avoided by the man not wilfully seeking trouble, but the genius of American designers and engineers, backed up by several years of practical experience, has finally evolved plants made by several manufacturers, which under the right kind of management and when provided with the right kind of coal, give no more difficulty in operation than many steam plants.

The type of producer best adapted for plants of the size usually adapted for small pumping plants is the suction producer. In this, the air passing through the producer is caused to flow by the suction effect of the engine, which upon the suction stroke takes in a charge of gas. There is, therefore, no gas storage and the amount of air passed through the producer varies directly with the speed of the engine. The plant consists of (1) the producer proper, with its accessories, such as a blower and feed-hopper; (2) a vaporizer (usually) in which the hot gas coming from the producer is cooled by coming in contact with water-cooled surfaces; the air taken into the producer by suction being made to pass through the vaporizer, takes up moisture besides being heated, and thus increases the efficiency of gas production. After leaving the vaporizer, the gas passes into (3) the scrubber, where tarry substances and dust are removed by the gas coming in contact with a spray of water, and being made to pass through thick layers of moist coke. Leaving the scrubber, the gas next passes through (4) a purifier in which is excelsior, sawdust, and the like, intended to remove the moisture and any re-

maining suspended impurities. Anthracite coal and coke or charcoal are the fuels best adapted to be used in this type of producer, but bituminous producers are being experimented with by many of our foremost engineering establishments and it will doubtless be only a matter of time till the chief trouble now experienced in the use of bituminous coal will be removed, namely, the dust and tarry products formed which, unless effectually removed, prevent the satisfactory operation of the engine. The bituminous producers so far devised have proven quite reliable, but their cost is very much greater than the ordinary suction anthracite producer plant. The latter are made in sizes of not less than 25 horse-power, a complete plant and an engine of this size costing, approximately, $1,800 at the factory.

Conditions Warranting Adoption of Gas-Producer Plant.—The writer does not recommend this type of power plant except under these conditions:

1. When anthracite, coke, or charcoal are available, or a semi-anthracite, the equivalent of New Mexican Cerillos.

2. When the power required is in excess of 50 horse-power.

3. Where steam coal costs over $3.50 per ton, gasoline over 18 cents per gallon, distillate oils over 9 cents per gallon, and electricity is either not available or will cost on the average over 5 cents for horse-power hour.

4. When attendance of intelligence and skill is available to run it.

We caution the prospective plant owner against adopting a producer-gas power plant except after a most careful inquiry into its merits and defects as compared with other kinds of power, and he should be particularly careful not to base his judgment upon fuel economy alone, for

reliability or ability to pump water when crops most need it is worth more than all the coal which might be saved in a year's operation by the producer plant as compared with steam. The average pumping-plant operator can ill afford to lose a crop because he has a plant which fails him, largely for want of knowledge of how to run it, at the most critical time, probably, in the whole season. Men given to enthusiasm over new mechanical devices and methods are apt to regard the producer-gas plant as the key to the whole problem of cheap pumping and either purchase such a plant themselves or induce their neighbors to do so, although they have but the most meagre and superficial idea of the kind of fuel needed, the practical operating difficulties, and of the economic conditions which make such a plant needed or advisable.

Electric Motor Drive.—Practically all irrigation pumping plants with electric drive use, or will use, three-phase alternating current of frequency of 60 cycles. Below 25 horse-power the voltage commonly used is 220, but above that power 440 volt motors are usually adopted. For primary distribution, 66,000 and 44,000 volts is common practice over extensive districts, and there are a few large pumping plants taking power direct from such primary lines. The transformer-room equipment is, however, very complicated and expensive, consequently most pumping installations of moderate size should be designed, if possible, to receive current at 2,200 volts, the usual plan being for the plant to own the necessary transformers to step down this voltage to that of the motors, current being measured on the low-tension side.

Below 50 horse-power ordinary "squirrel-cage" induction motors are commonly used, but above that power "slip-ring" induction motors with starting rheostats should invariably be employed, owing to the excessive starting

current required by the "squirrel-cage" type in large sizes. Where a large number of induction motors are on a system, operating conditions frequently require the power company to insist on the adoption of synchronous motors in plants of large size. Such motors have desirable characteristics for pumping-plant operation, but require special starting apparatus, which makes them less convenient than an induction motor, and more expensive.

As to make, there is but little difference between small-size induction motors of different manufacturers, the chief consideration being one of sufficient provision for ventilation. It is of importance, therefore, with any make, that in locating motors in the plant, they be placed where there is ample air circulation, avoiding corners and small, boxlike shelters, etc. Although induction motors stand severe abuse they sometimes burn out through being too heavily overloaded and through prevention of air circulation by accumulations of oil-laden dust on the coils and in the ventilating ducts.

As to whether the motor should be direct- or belt-connected to the centrifugal pump, there is some chance for argument. It is sometimes impossible to get the correct speed when using a direct-connected small stock pump and motor, and to get this a belt-connected set is the only solution. A belt, however, is a constant source of trouble, expense, and energy loss. These are completely avoided in the direct-connected sets.

CHAPTER XIV

THE CENTRAL STATION PUMPING PLANT

Locations Suitable for Central Station Plants.—In various parts of the West are to be found large tracts of land in every way suitable for agriculture, but too remote from surface streams to make gravity irrigation possible. Not infrequently such tracts are found to overlie a subterranean water supply of sufficient magnitude and at such depth as to make it possible to irrigate all or a part of the tract by pumping.

Such tracts are: The country surrounding Portales, N. M., part of the Estancia and Mimbres Valleys of New Mexico, the Santa Clara Valley, Arizona; the Riverside district and the San Joachim and Sacramento Valleys of California; the Willamette Valley, Oregon, the Valley of the Arkansas in Kansas and Colorado, and various others. Where topographic, hydrographic, agricultural, and economic conditions all favor the development of such sections or tracts by pumping, it is generally recognized as probable, at least, that much the cheaper and more economical scheme of reclamation is by a series of pumping plants scattered over the tract, each driven by power generated at a central plant rather than the same number of individual plants, each generating power by a small engine, perhaps very wasteful of fuel. At the central plant large power units being used, advantage may be taken of the most up-to-date and economical machinery and thus power may be generated and distributed to the separate plants at considerably less than it would cost the individual owner to generate it himself.

Conditions Governing Feasibility.—The feasibility of such a plant depends upon a number of conditions, of which we may mention the following:

(a) Adequacy and chemical character of water supply.
(b) Depth of water supply and probable total head to be pumped against.
(c) Suitability of tract for agricultural purposes.
(d) Shipping and marketing facilities.
(e) Size and shape of tract as governing cost of distribution lines and transmission losses.
(f) Ownership of tract.
(g) Possibilities of co-operation in case of private ownership of land and desirability of local ownership and control.
(h) Fuels obtainable and price delivered.
(i) Possibility of utilizing power at times other than during pumping season, *e.g.*, beet sugar and canning industries, city light and power, interurban transportation, general manufacturing, and other purposes requiring power.

It will be seen at once from a consideration of these conditions that a decision as to the feasibility of the central pumping plant must be based upon a broad study of a large number of more or less closely related subjects, all of which have an important bearing upon the feasibility of such a project. It is, therefore, not a matter to be decided offhand, and parties interested in the development of such a project should call to their aid the services of a competent engineer, who is familiar not only with the engineering features of such a scheme, but who also understands thoroughly the irrigation side of the problem. He should be required to inquire carefully into all sources of information and present a report covering essentially the points men-

tioned on page 186, besides giving his opinion as to the practicability and feasibility of the project. Upon such a report, if favorable, local parties will be warranted in vigorously furthering the scheme and with such a report, if it is desirable or necessary to introduce outside capital, there is much greater chance of interesting the careful investor or capitalist than by setting before him a mass of glittering generalities, guesses, and assumptions.

(a) **Adequacy of Supply.**—Naturally the first question of importance arising is as to the source of supply and its adequacy to the purposes of the project. Where a surface stream is to be used, simple measurements and records of stream flow will give the desired information as to available supply, but where an underground supply is to be developed the matter is largely mere conjecture when considering the possible demands for a large acreage. Existing wells in the tract, if any, should be investigated, and, if possible, their maximum capacity ascertained. If no suitable wells are available, test wells should be sunk and such temporary machinery be installed as will enable a test to be made not only of the flow, but of the draw-down at various flows, and of the saline ingredients at various depths. If the saline contents exceed 4,000 parts in 1,000,000, it is doubtful if the water could be used with success in irrigation. In the event of an excess of salts in the water at one level, it is frequently possible, by going deeper, to strike other strata in which the salty ingredients are so small as to be harmless.

Regarding the total amount of water required over the tract at any given time, it will be found an extremely difficult matter to arrive at any very satisfactory estimate. If the tract be divided up into a large number of small holdings and only one crop is grown, it is not unlikely, unless a very unusual degree of co-operation and organi-

zation exists, that all will require water simultaneously, making a very serious draft upon the underground supply and a severe demand upon the power station, not only by reason of the large number of pumps in operation at the same time, but also because the draw-down is likely to be increased considerably, shortly after pumping begins. Diversified crops and a centralized distribution, whereby the periods of demand for power will be more constant, is something which is imperative in economical operation of a central power station for pumping and is a matter which should be well understood by all interested parties.

The value of diversified crops in increasing the yearly load factor can best be shown by an example. Let us assume an area of 10,000 acres planted in crops as follows:

3,000 acres in alfalfa,
3,000 acres in orchard,
3,000 acres in small grains, etc.,
1,000 acres in melons and truck gardens.

These areas may be assumed as divided into a large number of small holdings, but since, under ordinary circumstances, each crop over the entire district will need water simultaneously, it is probably equivalent to a single holding. This statement may need some modification in practice, since not always will the judgment as to a crop's moisture requirements be unanimous. Among the more skilful and experienced irrigators there is, however, surprising unanimity of opinion as to the time for irrigation, as has been proven time and again in the management of irrigation enterprises to the dismay of managers, who for some reason might happen to be ill-prepared for large and sudden demands for water. Upon the above assumption, however, we may construct the following diagrams, which represent days of the irrigation system on the horizontal

axis and acre-feet on the vertical axis. Sections 1 to 4 represent the individual weekly requirements of the different crops, while section 5 represents the total amount to be supplied the entire area from week to week.

As will be seen from the diagram, the total water requirement for the entire acreage under diversified crops

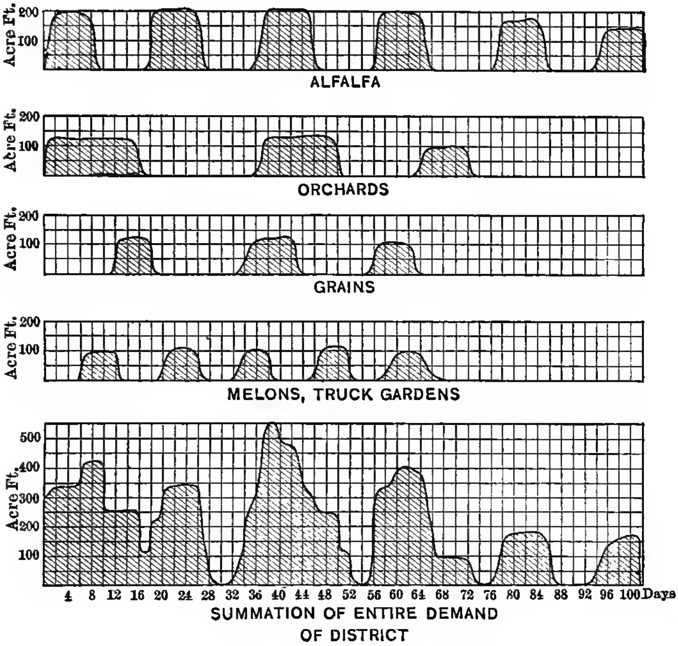


DIAGRAM 24

is much less irregular than the individual requirement of any particular crop, and the maximum total amount required, which governs the maximum power requirement and therefore the size of the central station equipment, is 16 per cent. less than though the entire area was in alfalfa. Such diagrams, compiled from the best available

information as to number of irrigations and periods between same and the probable water requirement for such crops as may probably be grown successfully in the district in question, should always be used to assist in forming an intelligent estimate of the total water requirement, and, therefore, the probable power requirement when the head is determined.

(b) **Head.**—We have already considered the question of draw-down and of static and friction head, so that when the average depth to water is known, it may be possible to estimate with some degree of accuracy that total head against which the water must be pumped. This will, of course, be an average for the district, since the ground-water plane being practically level, the static head will naturally vary with the topography and the total head on some quarter sections will be very much different from that on others in the same section, particularly in a rolling country.

Now arises the important question as to what crops may be grown with profit, using water pumped through the average head just estimated. This is really the crux of the whole matter, and involves in its solution not only a fair estimate of yields, producing costs, shipping costs, and market rates, but also an approximately correct idea of the cost of producing and distributing electric power over the area in question.

The best way of attacking this problem is to determine first the approximate cost of delivering an acre-foot of water at the surface for an acreage of a specified amount, using an average power cost, and taking into account all legitimate expenses chargeable to pumping plant. In estimates and calculations on this problem, it should be considered from the standpoint of the individual owner of small means, who is the one most likely to be attracted

by the irrigation pumping proposition. This problem has been analyzed in Chapter XI, headed "The Question of Cost and Profit on a Small Farm Irrigated by Pumped Water."

(c) **Suitability of Tract for Agricultural Purposes.**—This had best be determined, if in an absolutely new country, by the character of the native vegetation and by the depth and physical character of soil as determined by borings and test pits in different localities. Samples of the soil should be sent to the State Agricultural Experiment Station for chemical analysis, and an opinion obtained as to its value for agricultural purposes, while if time and opportunity permit it may be well, also, to have an agricultural expert go over the ground and give his opinion as to its suitability for the proposed purpose. In case agriculture of any kind has been carried on in the tract or upon adjoining tracts of like character not too far distant to present materially different climatic and soil conditions, it will be necessary to obtain, if possible, full information as to feasible crops, yields, action of soil under irrigation, *i.e.*, whether easy or difficult to irrigate, etc. The opinion of experienced irrigators on the tract or in vicinity should be given great weight, usually, on general questions of methods of irrigation.

(d) **Shipping and Marketing Facilities.**—A very important consideration in connection with the success of any project, except where it is so fortunately located as to be within hauling distance of some market big enough to absorb the entire product, is evidently the provision for getting the product to market cheaply and quickly. In the case of perishable products, like melons and garden vegetables, some well-organized shippers' association is necessary to handle the product successfully, and of course it goes without saying that, in such cases, the tract must

have railroad facilities. A wagon haul of more than 3 miles is usually fatal to melons and a haul of as low as 5 miles with alfalfa will pare down the profits materially. It is well, therefore, to canvass the question of markets and shipping facilities pretty thoroughly in a report, and state what market is available or may be developed and how reached. This matter, while more one of economics than engineering, cannot be neglected by any engineer who attempts to present a fair and unbiased report upon the merits of an irrigation enterprise, either for his clients or for the general public. The history of the West is replete with instances where engineers have considered merely the engineering features of irrigation enterprises, and have ignored the equally important question of whether it will probably pay their clients to finance the undertaking, and the general public to attempt to farm the lands.

(e) **Size and Shape of Tract.**—Where electricity is to be generated and transmitted from a central station, it is of very considerable importance that the points at which the power is to be used shall be compactly grouped. This requires, first, that the lands irrigated shall preferably be in one body and not in isolated or individual tracts; secondly that the tract shall not be in the shape of a long, narrow strip. The reason for this, obviously, is that the more closely grouped the pumping-plants are, and the closer they are to the power-station, the less is going to be the cost of transmission lines and the less the transmission losses.

(f) **Ownership of Tract.**—Central station pumping plants may be financed and installed in one of several ways. First, by the co-operation of a group of farmers who actually own the land. In this case the number of farmers must be sufficient, the land controlled sufficient in acreage, and sufficiently contiguous to make central station pumping evidently worth while, by which we mean that unless the

acreage combined is in excess of 1,000 acres in one body, a central station proposition is, at least, doubtful. Second, the scheme may be promoted by a company which endeavors to furnish power to individual pumping-plant owners, charging upon the basis of the power used. In this case, the same caution must apply as has been found necessary in the promotion of gravity irrigation schemes, namely, that the only safe course for any irrigation development proposition is to own at least one-half of the land to which the water is to be applied, making profits sufficient to pay for the initial investment out of the rise in the value of the land to which water may be applied. The company which has no load other than a pumping load and which depends for its revenues solely upon the sale of power will soon find itself in the same financial condition as have many irrigation companies which put large sums of money into dams, reservoirs, and distribution systems, and merely sold water to irrigators at so much per acre-foot. Very few, if any, such enterprises paid interest on the capital invested. The only entirely satisfactory basis upon which a company may undertake a central station pumping project, is first to acquire at, say, not over $15 per acre, a suitable tract of dry land, and develop same ready for occupancy and irrigation by prospective farmers to whom it is sold on a basis of double or treble the original cost under a contract providing for payment in a term of years, and providing further that the central power-station property shall eventually pass into the control of the landholders. Where, however, the pumping load is merely incidental or additional to the existing load, or that which it is proposed to develop, it is not so essential for the company to own a tract of land, but, nevertheless, it is always a wise precaution.

(g) **Possibilities of Co-operation, etc.**—Where a company already established proposes to furnish power to the

owners of lands for pumping purposes, it will be found essential in more or less extensive projects to draw up contracts in which the time of day during which power will be supplied for pumping is expressly agreed upon. It will also be essential to enlist the co-operation of these owners to reduce the peak load by dividing themselves into districts, each of which will use power when irrigation is needed, on certain days of the week, thus avoiding an overlapping of demands, which it might exceed the overload capacity of the central plant to supply, and which would invariably result in dissatisfaction among the pumping-plant operators, and an unfortunate resentment against the company.

(h) **Fuels and Price.**—The question of fuel is an important one in connection with central station pumping, and is a matter to be considered carefully in deciding upon the most suitable central station equipment. The various fuels have been discussed previously, as well as have the prime movers in which they would be used, hence it is unnecessary to more than mention here the connection of the fuel question with the more general study of the feasibility of a central station for pumping.

Where water power may be developed within 50 miles of the irrigation project this may be by far the more economical power to use under conditions favoring easy construction of the electric generating plant.

Pumping Season.—The greatest danger to the success of an electrical pumping-plant project is in the brevity of the season during which power for pumps is required, and excessive peak loads. From 90 to 105 days of the year is the period during which pumps may be run for irrigation purposes and except under the most skilful management, even with the most helpful co-operation of the plant operators, the load factor during these 90 to 105 days is likely

to be 100 per cent., that is, the demand for power may at times (when every one is irrigating) be equal to the combined horse-power of every plant in the project. If, for instance, there were 40 plants, each requiring 25 horse-power, the total load might be about 1,000 horse-power for most of the time, or, as shown by Diagram 24 on page 189, there would, even with diversified crops, be occasions for a week at a time when the entire series of plants would be in operation. Thus we have a condition which every experienced power engineer seeks, if possible, to avoid, namely, a plant of large station capacity, but of exceeding low yearly load factor. If the plant is used for irrigation alone it will stand idle for over two-thirds of the year. Common business prudence, therefore, suggests that some use be found for the plant during the remainder of the year. In well-settled localities there will likely be demand for power in lighting, in power purposes on the farms, and possibly in industrial enterprises of various kinds, and in street or interurban railway service. The lighting load is one which will not necessarily add to the peak load during the pumping season, but it must be noted that industrial power and railway requirements will add to the maximum capacity of the plant, since the requirement is likely to be constant throughout the year. The really desirable kind of load to develop is one which is not coincident with the pumping load, and this may be found in such service as supplying power for beet-sugar manufacture and canning factories. Indeed, it would seem a very desirable phase of the work of a beet-sugar factory to utilize its boiler plant during the period in which it would otherwise be idle in furnishing power for pumping, lighting, and general power purposes, if situated in a region where water-power is not available, and where lands desirable for beet raising, but above existing canals, could yet

be irrigated by pumps driven by power generated at the factory. The same observation holds in regard to the usual canning factory or any concern using steam and power in large quantities for only a brief period each year.

In the Snake River Valley where hydro-electric power is used in large amounts for pumping from the river and canals, the power companies make a special rate for heating of residences and buildings by electricity, thus providing a source of income during the fall and winter.

CHAPTER XV

WINDMILLS

The Field of the Windmill in Irrigation.—Any discussion of pumping for irrigation would be incomplete without some reference to the use of windmills. Although windmills cannot possibly be regarded as feasible or economical of use for the areas, quantities of water, and heads contemplated by our previous discussion, the windmill has a very useful field and is a most important feature of certain classes of Western agriculture. Its most conspicuous service in recent years has been in the aid of dry-farming; indeed, it seriously may be doubted if without the small truck or garden patch and the domestic water supply made possible by the windmill, even a bare existence would have been the reward of those hardy pioneers who have shown up the possibilities of dry farming. It is an unquestioned fact, as proved by the experience of all who have tried it, that to make life endurable on the dry farm and to have some means of tiding over the unusually dry and unproductive years, there must be some independent means of water supply sufficient to irrigate three, and preferably five or seven, acres of truck garden and alfalfa. The products of such an acreage may be the sole support of the dry farmers' family and stock during those off years which must be expected, however firm may be the prevailing belief as to a permanent change in climate.

For the development of the water supply, some have installed power-pumping plants, but the majority favor a windmill plant, because of its simplicity and apparent small operating expense. Another important field of use-

fulness for the windmill in irrigation is in connection with the development of small orchard tracts in the suburbs of many of the Western cities. Here suitable tracts may frequently be acquired on the mesas or benches adjacent to the town, which are not supplied by high-line canals, and yet where a water supply may be developed within a depth of 100 feet. Such tracts possess the evident advantage of convenience to market, and many men are trying the experiment of putting small tracts of 5 to 10 acres into orchards of peach, apple, pear trees, etc., irrigating by water pumped by windmill. Wind power is used almost exclusively for pumping the water supply of stock on the great ranges of the Southwest. This is a development of the last 10 or 15 years, and has enabled cattle to be grazed on vast areas formerly untouched because of distance from nearest water hole or surface-water supply. The discovery of water beneath portions of the great plains of Texas, and other sections long considered hopelessly dry, with the subsequent rapid dry-farming development, is the result of the successful attempt of cattlemen to erect windmills for stock watering, and thus extend the ranges. Altogether, it may be said that wind power offers a very interesting and possibly the ultimate solution of the problem of developing the agricultural possibilities of the great plains country by pumping. Undoubtedly, as fuel increases in price, as it will, at an increasing rate as the years go on, manufacturers will be justified in introducing improvements in wind engines, which will increase their power and general suitability to the requirements of pumping, these improvements now being delayed, owing to the impossibility of constructing windmills of the power of small gasoline engines, which will anywhere near approach the price of the latter.

Kind of Mills.—It is not our purpose to enter into any

technical discussion of windmills, and it will suffice merely to mention some of the more important types and classes of mills as respects their structure.

Size.—Windmills are rated according to the diameter of the wind wheel, which in standard American machines may vary from 8 to 16 feet by intervals of 2 feet. Sizes larger than 16 feet are in use by railroad companies, and in some localities, as, for instance, in certain parts of California, very large home-made wheels upward of 25 feet in diameter are in use. The Dutch type of mill has a four-vane wheel of very large diameter, but there are only one or two examples of this type in this country, and it is of no commercial importance whatever. As to the material, the more common examples of modern windmills have galvanized pressed-steel vanes in the wheel, but there are also on the market very serviceable mills with wooden vanes. Under modern methods of construction, using light structural steel shapes and pressed-steel vanes, etc., there is no reason why a steel mill cannot be made as light as the wooden type, besides being stronger and more durable.

Governing.—In order to prevent the mill from being blown down in high winds, which would happen if the full sail area of the wheel were opposed to the wind at all times, various schemes of governing have been adopted by different makers. The most common scheme is to turn the wheel with its edge to the wind in high velocities by either a governing vane which functions when the air pressure on its area exceeds a predetermined limit as measured by an opposed spring; or in one make of mill the axis of the wheel is set eccentrically to the vertical axis of rotation, and the air pressure on the wheel area itself forces the whole head to rotate on the vertical axis against the opposition of the tail as determined by a spring, the tension of which can be adjusted. Another method is one in which the vanes are

rotated about their long axis, so as to oppose merely their edges to high winds, while in still another scheme, the vanes are hinged at the periphery of the wheel, and in high winds the vanes move into a position with their axes more or less closely parallel with the direction of the wind. Obviously in the last two cases the plane of the wheel remains perpendicular to the direction of the wind, and the mill is not usually provided with a tail or rudder.

Another important difference between types of mills is in respect to the manner in which the power is transmitted. With some mills the power is transmitted to a pump rod directly by a pitman connected to a crank on the main shaft of the wind wheel. In another class, known as geared mills, the pump rod is attached to a pitman connected to a crank pin on a gear which meshes with a pinion on the wind-wheel shaft. The usual gear ratio is from 3 or 4 to 1, thus making the number of pump double strokes from one-third to one-fourth the number of revolutions of the wind wheel.

In another type of mill, the wind wheel is connected by a bevel gear and pinion to a vertical shaft, which by means of a second set of bevel gears at the base of the tower may transmit power to a horizontal shaft to which the pumping machinery may be attached. This is known as a power mill, and is useful for other purposes than pumping, though there is some loss of power through friction in the two sets of gearing necessary, which is avoided with the pump-rod types.

The Selection of a Mill.—It is useless to make many specific recommendations concerning the selection of a mill, since it is to be expected that the makers' statements in advertising literature very frequently will be taken without the necessary "grain of salt," and just as often a mill will be bought upon its reputation or upon the en-

dorsement of a neighbor. We may, however, lay down these general rules, which should govern one in buying any mill.

(1) Power of Mill.—A mill is wanted that will deliver the maximum possible quantity of water pumped from a predetermined depth with such wind conditions as prevail in the given locality.

(2) Governing.—A mill is wanted which will govern properly in high winds with a minimum of personal attention.

(3) Strength and Design.—A mill is wanted in which the parts are of ample strength, but not necessarily heavy and massive.

(4) Bearings and Oiling Devices.—A mill is wanted which has ample bearings properly fitted and provided with oiling devices of sufficient capacity and such type that the mill will not have to be oiled oftener than once a month.

(5) Pump Cylinder.—A pump cylinder is wanted of capacity that will load the mill properly and which is so designed and made of such material as will give a maximum length of service with the least wear of working barrel and valves.

The points above cover the general specifications of importance to consider in the purchase of a mill as regards the size of wheel and the pump cylinder, together with the design and construction of the essential working parts. Many windmills in standard sizes and prices are now on the market which conform to the desired character of construction indicated. When the intending purchaser has decided upon the size and type of mill he needs, his only care will be to see that he does not buy a low-priced mill in which the construction does not conform to what has come to be regarded as standard.

Power of Mill.—We have in this matter many factors

involved which it has been the endeavor of numerous experimenters to discover and correlate. Among the published researches which concern the power of wind wheels, we may mention those of Wolf, Perry, E. C. Murphy, Hood, Fargusson, King, and Fuller, in this country, and of Chatterton in India, and Ringelmann in France. The endeavor of these various experimenters has been to derive some relation between the power of a mill measured in horsepower, the diameter and type of wheel, and the velocity of the wind.

Their work has very clearly demonstrated the extreme complexity of the problem, but some important facts have been established which have an immediate bearing upon the practical problem of so proportioning the load and size of a mill for a given locality that the maximum possible amount of work may be accomplished by the mill in a given time. The first matter to which attention should be given is the wind record for the specific locality, or at the nearest Weather Bureau station where records are kept. Such a record for Cheyenne, Wyoming, taken from Farmer's Bulletin 394 on Windmills, shows that the average wind velocities during a period of five years for the months April–September, inclusive, were as follows:

Hours per Month during which the Wind's Velocity per Hour was

Miles per Hour	0 to 5	6–10	11–15	16–20	21–25	26–30	31–35	36–40	40 and over.
Hours	209.9	283.6	142.2	62.3	22.6	9.58	3.4	1.2	.4

A similar record may be obtained from any Weather Bureau observation office, and should be obtained if a study similar to the following is intended for a specific locality. The following is a table similar to that above, and gives results of observations of wind velocities at

Dodge City, Kansas, for seven years, as compiled by Mr. Murphy:

Hours per Month during which the Wind's Velocity per Hour was

Miles per hour..	0 to 5	6–10	11–15	16–20	21–25	26–30	31 and over
Hours.........	140	198	157	109	72	34	22

The most conspicuous fact apparent from the above tables is the great preponderance of time during which comparatively low wind velocities prevail even in so notably windy a climate as that of Wyoming. It is evident, therefore, that the mill will be best fitted for accomplishing useful work which will make use of the low wind velocities, for, if these can be determined, then some estimate is possible of the amount of water which a mill may pump in a season if the depth to water and the friction and hydrostatic head are known, as well as the size of the pump cylinder.

The diagrams on page 204, taken from Farmer's Bulletin 394, show certain characteristics of a 14-foot power mill.

The first of these diagrams shows the most important fact to be noted in connection with a study of windmills, namely, that the horse-power which the windmill may deliver is dependent upon the load placed on the mill. Thus in Diagram 25, the curves marked A, B, C, etc., correspond to what would in effect follow a progressive increase in the size of pump cylinder, where the mill is used for pumping. Take, for example, curve A. This would correspond to a pump cylinder of small diameter, so that the number of pounds of water lifted per one stroke of pump is small. It will be noted that a mill with this load would start in a wind of about 4 miles per hour, and, as the wind velocity increased, the horse-power output would

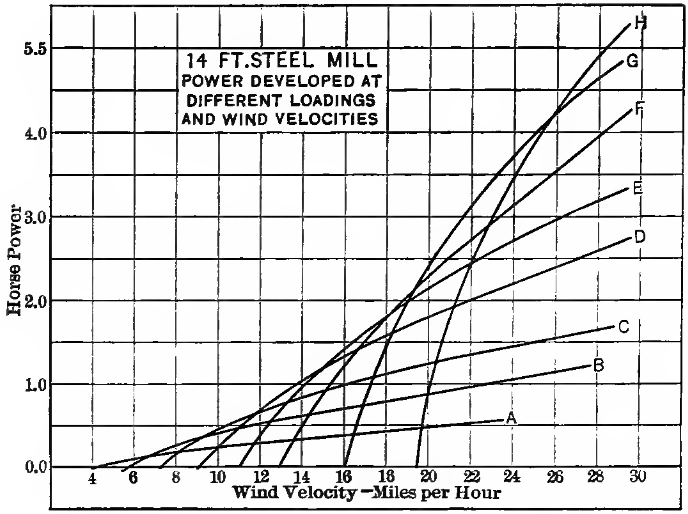


DIAGRAM 25

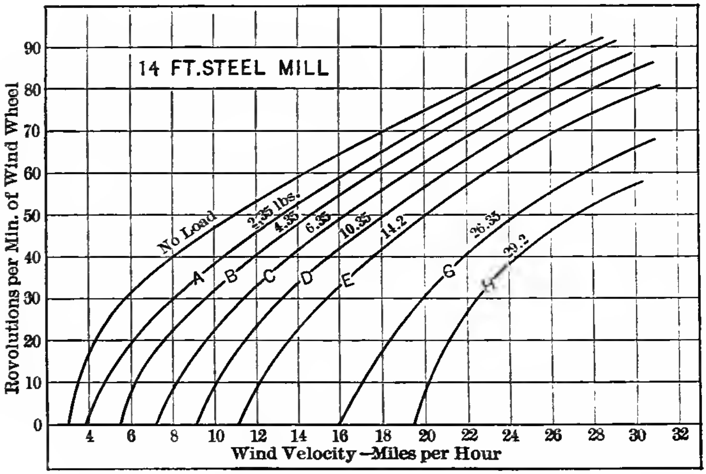


DIAGRAM 26

increase very slowly. As will be seen from curve A in Diagram 26, the speed of the wheel would increase very rapidly at this load. Refer now to the curve marked H, in both diagrams. This would correspond to a very much larger pump cylinder and a greater weight of water lifted each pump stroke. As will be seen in Diagram 26, the mill would not start with this load until the wind had attained a velocity of nearly 20 miles per hour, but a slight increase in wind velocity would be accompanied by a very rapid increase in delivered horse-power, so that at a velocity of 26 miles per hour the mill thus heavily loaded would deliver nearly seven times the horse-power of the same mill loaded as in the first case and at the same wind velocity. The speed of the mill would also be 40 revolutions less per minute for the heavier load. These diagrams, therefore, illustrate a very important fact or principle, viz., that the power output of a mill in a given wind velocity varies with the load upon it and that at the higher velocities of wind the heavily loaded mill gives a greater horse-power at a more desirable speed for pumping purposes. On the other hand, the heavily loaded mill will deliver no power whatever in moderate winds, and requires a comparatively high wind in which to start. This fact has been appreciated for some time and various devices have been invented which would automatically vary the load of a mill according to the wind velocity. A perfectly acting device of this sort would evidently enable the mill to deliver a maximum possible power output in the course of a season, the mill always operating at the most efficient load no matter what the wind velocity. Unfortunately, such an ideal device has not been made, and it involves mechanical difficulties not likely to be surmounted for some time to come. The best that can be done under the circumstances, therefore, in view of this peculiar characteristic of the wind

wheel, is to select a pump of such size that for the particular wind conditions of any given locality the mill may be expected to deliver the greatest possible quantity of water in a season. The selection of this pump size involves a rather extended series of calculations and comparisons, which probably may best be illustrated by a concrete example.

The Problem of Determining Best Diameter of Pump Cylinders, Concrete Case.—Let it be supposed that it is desired to know what pump should be used with a 12-foot mill of the same type used in the experiments from which the above diagrams were deduced; where it is desired to pump water from a depth of 40 feet and discharge it into a reservoir 6 feet deep. Assuming a draw-down of 5 feet and a friction head of 3 feet, the total head to be pumped against would be $40 + 6 + 5 + 3 = 54$ feet.

The following work, upon which will be based the determination of the most effective pump size, will rest upon certain published results of Professor Murphy on a 12-foot mill, to which he attached a friction brake in such a way that the performance of the wheel at different brake loads and at different wind velocities could be accurately determined. These results, which give the actual power of the wheel, can be used for a comparison of direct stroke and geared mills as well. The diagrams which follow are derived from the results and diagrams given by the authority mentioned. Diagram 27 gives the relation between wind velocity and the revolutions per minute of the wind wheel for different loads as expressed by the number of foot-pounds of work accomplished per one revolution of the wind wheel.

The Size of Pump for Direct-Acting Mill.—Windmills are usually arranged for different lengths of pump stroke, and for the present example for a 12-foot mill this will be

taken at 10 inches. The sizes of pump cylinder from which a selection may be made are assumed as of diameters of 4, 5, 6, and 7 inches, for the direct-stroke mill. A slip of 15 per cent. will be assumed for the pump, which value would represent one in very good condition, and a mechanical efficiency of 80 per cent. for the mill that is, 80 per

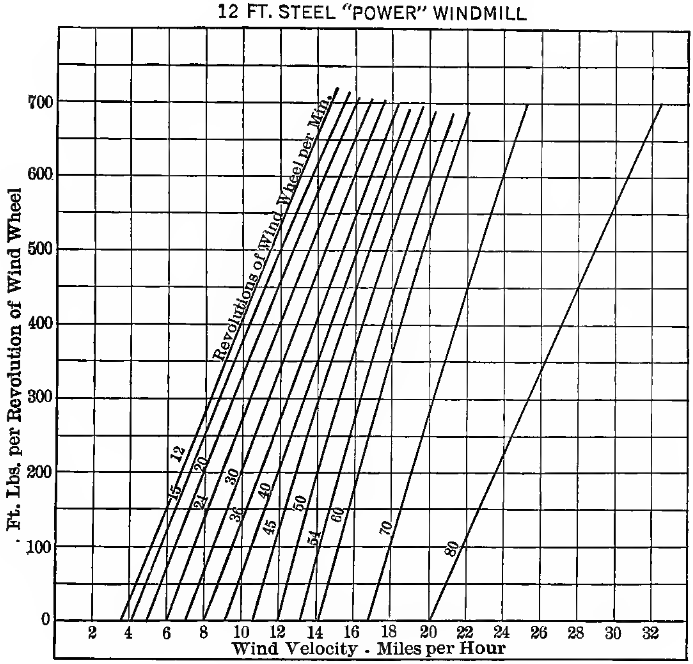


DIAGRAM 27

cent. of the possible work of the wheel will be assumed as available at the pump. Using the value for slip just mentioned, the following table shows the capacity of different diameters of pump cylinder in acre-feet per hour at different numbers of strokes per minute:

TABLE XI

CAPACITY OF DIFFERENT SIZES OF PUMP CYLINDERS, WITH 15 PER CENT. SLIP

ACRE-FEET PER HOUR

Pump	Strokes per Minute						
	20	30	40	50	60	70	80
7 x 10 inches........	.0052	.0078	.0104	.0130	.0156	.0182	.0208
6 x 10 inches........	.0038	.0057	.0076	.0095	.0114	.0133	.0152
5 x 10 inches........	.0027	.0039	.0054	.0065	.0081	.0091	.0108
4 x 10 inches........	.0017	.0025	.0034	.0042	.0051	.0059	.0068

It is, of course, obvious that the higher speeds, that is, those much above 40 strokes per minute, are impracticable, owing to severe inertia effects. The whole range of speed indicated will, however, be used for illustration.

Using the sizes of cylinders above given, the following table gives the foot-pounds developed per revolution of wind wheel for a 54-foot total lift with 15 per cent. slip and 80 per cent. mechanical efficiency.

TABLE XII

FOOT-POUNDS OF WORK PER ONE REVOLUTION OF WIND WHEEL

Size of Pump	4 x 10 ins.	5 x 10 ins.	6 x 10 ins.	7 x 10 ins.	8 x 10 ins.
Ft.-lbs. per rev......	260	430	580	800	1,050

Using the values of foot-pounds per revolution of wind wheel as an argument, we may now by use of Diagram 27 determine the wind velocity which is necessary to give the required speed of the wind wheel. These values are shown in the following table:

TABLE XIII

Twelve-Foot Direct-Stroke Mill

Wind Velocities in Miles per Hour which Will Turn Wind Wheel at Various Speeds when Using Various Sizes of Pump Cylinders

Size of Pump	Revolutions of Wind Wheel per Minute						
	20	30	40	50	60	70	80
7 x 10 inches........	17	19	20	22	24	....	....
6 x 10 inches........	14	15.5	17	18.5	20.5	23.5	....
5 x 10 inches........	11.5	13.5	15	16.5	18.5	20	....
4 x 10 inches........	9	11	12.6	14.5	17	20	25

Using the values of wind velocity as above given, we now refer to the weather records and determine the number of hours per season during which these velocities are found to occur. These are shown in the following table:

TABLE XIV

Showing Number of Hours per Season During which Wind Wheel Will Rotate at Given Speed with Given Load

Twelve-Foot Direct-Stroke Mill

Size of Pump	Revolutions of Wind Wheel per Minute						
	20	30	40	50	60	70	80
7 x 10 inches.......	653	653	653	430	430	...	...
6 x 10 inches.......	944	944	653	653	653	430	...
5 x 10 inches.......	944	944	944	653	653	430	...
4 x 10 inches.......	1,187	944	944	944	653	653	430

Note.—The blank spaces in each of the last two tables indicate that the wind velocities are above 25 miles per hour, at which velocity, ordinarily, mills are supposed to be thrown out of action by the governing device to prevent injury to the mill and tower.

If the number of hours during which a certain wind velocity occurs be now multiplied by the average hourly discharge in acre-feet, for the pump speeds corresponding to that load and wind velocity, we may construct therefrom the following table:

TABLE XV

TWELVE-FOOT DIRECT-STROKE MILL. 54-FEET TOTAL HEAD

AVERAGE QUANTITIES PUMPED PER SEASON IN ACRE-FEET

Size of Pump	Hours per Season				Totals
	1,187	944	653	430	
7 x 10 inches	...	...	5.1	6.1	11.2
6 x 10 inches	...	4.5	6.2	5.7	16.4
5 x 10 inches	...	3.7	4.7	3.9	12.3
4 x 10 inches	1.9	3.2	3.5	2.9	11.5

The fact now becomes apparent, as seen from an inspection of the total quantities pumped in a season, given in the last column of the above table, that the 6- by 10-inch pump is much the most efficient size to use, since by it, under the local conditions of wind movement and head pumped against, the largest quantity of water is delivered. As a matter of fact, this would have to be modified in the practical case, since if a pump of this stroke and diameter were used, the mill would have to be arranged to cut out at lower wind velocities to avoid the danger of operation at high pump speeds for considerable periods. If this size of pump were used and it were proposed to prevent the pump from operating over 50 strokes per minute, then, as shown by the above table of wind velocities versus loads and speeds, Table XIII, the governor would have to be adjusted to throw the mill out of action at wind velocities of over

19 miles per hour. This limitation on rotative speed would cause a loss of 5.7 acre-feet per season with the 6- by 10-inch pump, 4.4 acre-feet for the 5- by 10-inch, and 6.4 acre-feet for the 4- by 10-inch. The relative quantities pumped per season would then be shown by the following table:

TABLE XVI

TWELVE-FOOT DIRECT-STROKE MILL. 54-FEET TOTAL HEAD

Size of pump....	7 x 10 ins.	6 x 10 ins.	5 x 10 ins.	4 x 10 ins.
Acre-ft. per season	11.2	10.7	7.9	5.1

Upon this basis it appears that there is but little difference between the 7- by 10-inch and the 6- by 10-inch pumps. Doubtless an investigation similar to the preceding for pumps of different strokes would show some combination of stroke and diameter, which, without exceeding the safe pump speed, would give a greater seasonal capacity than that just found. One fact shown by the above tables confirms that already well known by pump and windmill manufacturers and those who have investigated the performance of windmills, namely, that the direct-stroke mill is best adapted to localities where the average wind velocity is high and of long duration.

Size of Pump for Geared Mills.—The same methods and the same data will be taken for this example as in the preceding investigation for the direct-stroke mill. It is understood that in the geared type of mill the pump is driven by a pitman and pump rod connected to a crank shaft which rotates at less speed than the main shaft to which the wind wheel is attached. The speed reduction varies with different makers, but in the present case the speed of the pump shaft will be taken at one-third the

speed of the main shaft. Then the number of pump double strokes will be one-third the revolutions of the wind wheel. The introduction of the gearing thus necessary causes a friction loss both in the gearing and in the journals so that 60 per cent. of the power possible from the wind wheel will be assumed in this case as being available at the pump. For this investigation a greater number of pump diameters will be considered, but of the same stroke with one exception. The table on page 213 gives the sizes of pumps which will be tried, together with the foot-pounds of work corresponding to one revolution of the wind wheel, for a total pumping head of 54 feet.

Averaging the acre-feet discharged over the range of wind velocities which occur for the same number of hours per season and adding together the discharges for the several ranges, we obtain the total for the season. The 8″ x 10″ pump is found upon this basis to give the maximum, for wind velocities below 25 miles per hour.

By referring to the discussion of the direct-stroke mill, it will be seen that for the weather conditions of the example the difference between the performance of the direct and geared mills in this instance is not striking. Placing the results side by side, we have.

	Direct Stroke.	Geared.
Size of cylinder.............	7 x 10 ins.	8 x 10 ins.
Water-pumped acre-feet per season.................	11.2	10.5

Both mills would be adjusted to be thrown out of action at a wind velocity of about 25 miles. While there is a slight advantage, as above shown, for the direct-stroke mill, it is to be understood that this is due to the relatively high average wind velocity. For localities with lower average wind velocities the advantage would be quite

TABLE XVII

Size of Pump	5 x 10 ins.	6 x 10 ins.	7 x 10 ins.	8 x 10 ins.	10 x 10 ins.	10 x 12 ins.
Ft.-lbs. per one rev. of wind wheel	181	260	355	466	720	866

TABLE XVIII

12-Feet Geared Mill

CAPACITY OF SINGLE-ACTING PUMP IN ACRE-FEET PER HOUR FOR DIFFERENT SPEEDS OF WIND WHEEL 15 PER CENT. SLIP

Size of Pump	Revolutions of Wind Wheel per Minute									
	12	15	24	30	36	42	54	60	70	80
5 x 10 inches	.00050	.00066	.00106	.00133	.0016	.0018	.0024	.00266	.0031	.0035
6 x 10 inches	.00076	.00095	.0015	.0019	.0023	.0027	.0034	.0038	.0044	.0051
7 x 10 inches	.00104	.0013	.0021	.0026	.0031	.0036	.0047	.0052	.0061	.0069
8 x 10 inches	.00136	.0017	.0027	.0034	.0041	.0047	.0061	.0068	.0080	.0091
10 x 10 inches	.00210	.0026	.0042	.0053	.0064	.0074	.0096	.0106	.0125	.0142
10 x 12 inches	.00254	.0032	.0051	.0064	.0077	.0089	.0115	.0128	.0149	.0170

TABLE XIX

12-Feet Geared Mill. 54-Feet Total Pumping Head

TABLE SHOWING THE REQUIRED WIND VELOCITY TO MAINTAIN CERTAIN PUMP SPEEDS WITH DIFFERENT PUMP SIZES OR LOADS, THE HOURS PER SEASON DURING WHICH THE WIND VELOCITY IS MAINTAINED AND THE ACRE-FEET OF WATER PUMPED IN THIS TIME AT THIS SPEED

Size of Pump		Revolutions of Wind Wheel per Minute									
		12	15	24	30	36	42	54	60	70	80
		Pump Double Strokes per Minute									
		4	5	8	10	12	14	18	20	23	27
5 x 10 ins.	Wind velocity	6	7	8.5	10	11	11.7	15.5	16	19	23.5
	Hours per season	1,187	1,187	1,187	1,187	944	944	653	653	653	430
	Acre-feet	.63	.78	1.41	1.58	1.51	1.7	1.56	1.73	2.02	1.50
6 x 10 ins.	Wind velocity	7 8	8.0	10	11	12	13	16	19	20	25
	Hours per season	1,187	1,187	1,187	944	944	944	653	653	653	430
	Acre-feet	.91	1.13	1.78	1.80	2.17	2.55	2.22	2.48	2.87	2.19
7 x 10 ins.	Wind velocity	9	10	11	12	13	14	17	18	21	....
	Hours per season	1,187	1,187	944	944	944	944	653	653	430	....
	Acre-feet	1.25	1.54	1.98	2.45	2.93	3.40	3.07	3.40	2.61	....

8 x 10 ins.	Wind velocity	11	12	13	14	14.5	15	18	19	22	....
	Hours per season	944	944	944	944	944	944	653	653	430	....
	Acre-feet	1.28	1.60	2.55	3.20	3.86	4.44	4.00	4.45	3.44	....
10 x 10 ins.	Wind velocity	14	15	16	17	18	19	21	23	....	....
	Hours per season	944	944	653	653	653	653	430	430	....	....
	Acre-feet	1.98	2.45	2.74	3.46	4.19	4.84	4.13	4.56	....	....
10 x 12 ins.	Wind velocity	17	18	19	20	21	22	23	24	....	....
	Hours per season	653	653	653	653	430	430	430	430	....	....
	Acre-feet	1.66	2.09	3.30	4.20	3.20	3.82	4.90	5.50	....	....

marked in favor of the geared mill. While the foregoing analysis is long and tedious, it is of some advantage to know that even for a windmill there is a feasible method of calculating its optimum working conditions and proportioning the parts of the machine to fulfil those conditions. At present most calculations of windmill capacity are based on an estimated average wind velocity acting eight hours a day. Since the average assumed is generally high, and the time during which it is assumed to last is more than is customarily encountered, the quantities pumped according to manufacturers' estimates, are generally far in excess of that actually realized. It would seem that there is an opportunity for windmill manufacturers more generally to publish authoritative tests from which, when properly worked out, the average man who is going to put in a mill would have some guidance toward the selection of the right size of wheel and pump cylinder to give the optimum service.

The Pump Cylinder.—The character of the pumping portion of the windmill plant will vary with the kind of well from which the water is taken. For shallow depths, say 30 feet or less, the open well is much to be preferred, and in this well will be used an ordinary pump cylinder, discharging probably through a length of spiral riveted galvanized pipe to an outflow pipe at the surface. The pump cylinders in sizes up to 8-inch, are most usually of brass, above that of cast iron, and the valves are usually of the common leather flap type. For deeper wells where water is encountered at depths below 30 feet, the driven well is usually necessary, and this should always be provided with an ample strainer, preferably of as open a type as the character of the material will allow. The use of drive points is to be discouraged, owing to the limited capacity and the imminent possibility of early clogging and complete stoppage of flow.

Where the driven well is necessary, the best scheme is to use a drive-pipe of such size as will allow the couplings of a pipe of the same nominal size as the pump to be used to pass freely into and through the drive-pipe. Thus the couplings on 8-inch pipe have a nominal diameter of couplings of 9.19 inches, thus making it necessary to use a 10-inch pipe. The pump cylinder is attached to the bottom of a "drop pipe" of the same nominal diameter, and is lowered into the well section by section, the pump rods being connected as it goes. This enables the pump cylinder to be withdrawn when the valves need replacing or the piston needs repacking. In cheap installations and for small wells the rough drive-pipe itself is sometimes made to serve as a cylinder or working barrel and no "drop pipe" is used. Again, a thin brass lining is sometimes inserted in the well-casing and fastened at the desired depth by rubber rings or wedges, which it is difficult, if not impossible, ever to remove after once being placed. Such pumps, while cheap, cannot be considered as lasting, and when they do wear out, the well is practically useless, since it is extremely difficult to remove the bottom valve, and equally difficult to replace a brass liner.

For the deep bored or driven well, therefore, it is recommended that a unit working barrel be employed, of a size suited to the load which an investigation of the wind characteristics of the locality indicates may be used, and that this "working barrel" be attached to a "drop pipe" of the same nominal diameter held rigidly at the surface. At the surface, the drop pipe is generally screwed into a tee and a nipple placed above it of sufficient length to insure that there will be enough head to force water out through the outlet connected to the side branch of the tee. Water may be carried under pressure to a point some distance away by this method, without the use of a stuffing box.

For deep wells, a working barrel provided with ball valves is frequently preferred to the leather flap or metallic valve type of the ordinary cone seat. The writer knows of one instance in his own experience of such a cylinder working perfectly for more than five years under nearly 100-foot head.

APPENDIX

Partial list of manufacturers and dealers in machinery and appliances used in irrigation pumping.

Centrifugal Pumps

Allis-Chalmers Manufacturing Company, Milwaukee, Wis.
American Well Works, Aurora, Ill.
Buffalo Steam Pump Company, Buffalo, N. Y.
Byron Jackson Machine Works, San Francisco, Cal.
De Laval Steam Turbine Works, Trenton, N. J.
Krogh Manufacturing Company, San Francisco, Cal.
Lawrence Machine Company, Lawrence, Mass.
R. D. Wood & Company, Philadelphia, Pa.
Henry R. Worthington, New York, N. Y.

Piston and Plunger Pumps

American Well Works, Aurora, Ill.
Cook Well Company, St. Louis, Mo.
Deming Company, Salem, Ohio
Fairbanks Morse & Company, Chicago, Ill.
Goulds Manufacturing Company, Seneca Falls, Mass.
Keystone Pump Manufacturing Company, Beaver Falls, Pa.

Wood Stave Pipe

Pacific Tank and Pipe Company, San Francisco, Cal.
Washington Pipe and Foundry Company, Tacoma, Wash.
Redwood Manufacturers Company, San Francisco, Cal.
Portland Wood Pipe Company, Portland, Ore.

Spiral and Straight Riveted Pipe

American Spiral Pipe Works, Grant Works, Ill.
Merchant & Evans Company, Philadelphia, Pa. (Spiral.)
Power & Mining Machinery Company, Cudahy, Wis.
Tofts Structural Iron Works, Houston, Texas.
Union Iron Works, San Francisco, Cal.
Weigele Riveted Steel Pipe Works, Denver, Colo.
Western Pipe & Steel Company, Los Angeles, Cal.

Valves and Fittings

Crane Company, Chicago, Salt Lake City, etc.
Wm. Powell Company, Cincinnati, Ohio.
Chapman Valve Manufacturing Company, Indian Orchard, Mass.

Gates and Controlling Appliances

Hinman Hydraulic Manufacturing, Denver, Colo.
Coffin Valve Company, Boston, Mass.

Well Drilling Machinery and Apparatus

American Well Works, Aurora, Ill.
Keystone Driller Company, Beaver Falls, Pa.
Williams Brothers, Ithaca, N. Y.

Gasoline Engines

Dempster Mill Manufacturing Company, Beatrice, Neb.
Fairbanks Morse & Company, Chicago, Ill.
International Harvester Company, Chicago, Ill.
Otto Gas Engine Works, Philadelphia, Pa.
Stover Engine Works, Freeport, Ill.
Witte Iron Works Company, Kansas City, Mo.

Oil Engines

American Diesel Engine Company, St. Louis, Mo.
De La Vergne Machine Company, New York, N. Y.
Elyria Engine Company, Elyria, Ohio.
Fairbanks Morse & Company, Chicago, Ill.
Mietz Iron Foundry & Machine Works, New York, N. Y.
Western Gas Engine Works, Los Angeles, Cal.

Gas Producers

Fairbanks Morse & Company, Chicago, Ill.
Minneapolis Steel and Machinery Company, Minneapolis, Minn.
Rathbun Jones Engineering Company, Toledo, Ohio.
Weber Gas and Gasoline Engine Company, Kansas City, Mo.
Westinghouse Machine Company, Oil City, Pa.
R. D. Wood & Company, Philadelphia, Pa.

Electric Motors and Electrical Appliances

Allis-Chalmers Manufacturing Company, Milwaukee, Wis.
Fairbanks Morse & Company, Chicago, Ill.
General Electric Company, Schenectady, N. Y.
Reliance Electrical Company, St. Louis, Mo.
Wagner Electric Manufacturing Company, St. Louis, Mo.
Westinghouse Electric and Manufacturing Company, Pittsburg, Pa.

General Contractors for Complete Plants

Allis-Chalmers Manufacturing Company, Milwaukee, Wis.
Fairbanks Morse & Company, Chicago, Ill.
Hendrie & Boltoff, Denver, Colo.
Krakauer, Zork & Moye, El Paso, Texas.
Mine and Smelter Supply Company, Denver, Salt Lake City, El Paso.

INDEX